

Baryon-Baryon Interactions for $S=0,-1,-2,-3,-4$

Recent Nijmegen Extended-Soft-Core ESC08-models

Hyperon-Hyperon Interactions and Searches for
Exotic D-Hyperons in Nuclear Collisions

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1 Nijmegen ESC-models

Outline/Content Talk

- I Introduction: (i) objectives, (ii) channels, (iii) publications, (iv) role BB-models.
- II QCD: (i) meson-exchange, (ii) multi-gluon-exchange, (iii) quark-core effects.
- III ESC-models: (i) method analysis, (ii) dynamics (OBE, TME, MPE, etc.).
- IV NN-results: (i) fit NN-, YN-data, (ii) coupling constants, (iii) nuclear matter.
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- VI S=-1, YN-results: $\Lambda N, \Sigma N$.
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Acknowledgements:

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2 Nijmegen ESC-models

Recent Baryon-baryon ESC Interactions

- Extended-soft-core Baryon-baryon Model ESC04/08
- Recent publications ESC-model:
 - I, Nucleon-nucleon Interactions,
[Rijken, Phys.Rev. C73, 044007 \(2006\)](#)
 - II, Hyperon-nucleon Interactions,
[Rijken & Yamamoto, Phys.Rev. C73, 044008 \(2006\)](#)
 - III, $S = -2$ Hyperon-hyperon/nucleon Interactions,
[Rijken & Yamamoto, arXiv:nucl-th/060874 \(2006\)](#)
 - IV, Baryon-Baryon Interactions and Hypernuclei,
[Rijken & Nagels & Yamamoto, P.T.P. Suppl. 185 \(2011\)](#)
 - V, $S = 0, -1, -2$ Nucleon-/nucleon/hyperon Interactions,
[Rijken & Nagels & Yamamoto, to be published \(2012\)](#)
 - VI, $S = -3, -4$ Nucleon-/nucleon/hyperon Interactions,
[Rijken & Nagels, to be published \(2012\)](#)
- ESC08 = ESC04 + quark-core effects + ALS-corrections:
- ESC08: 1. $\Sigma^+ p(^3S_1, I = 3/2)$, large short-range repulsion
2. ΛN small hypernuclei LS-splittings

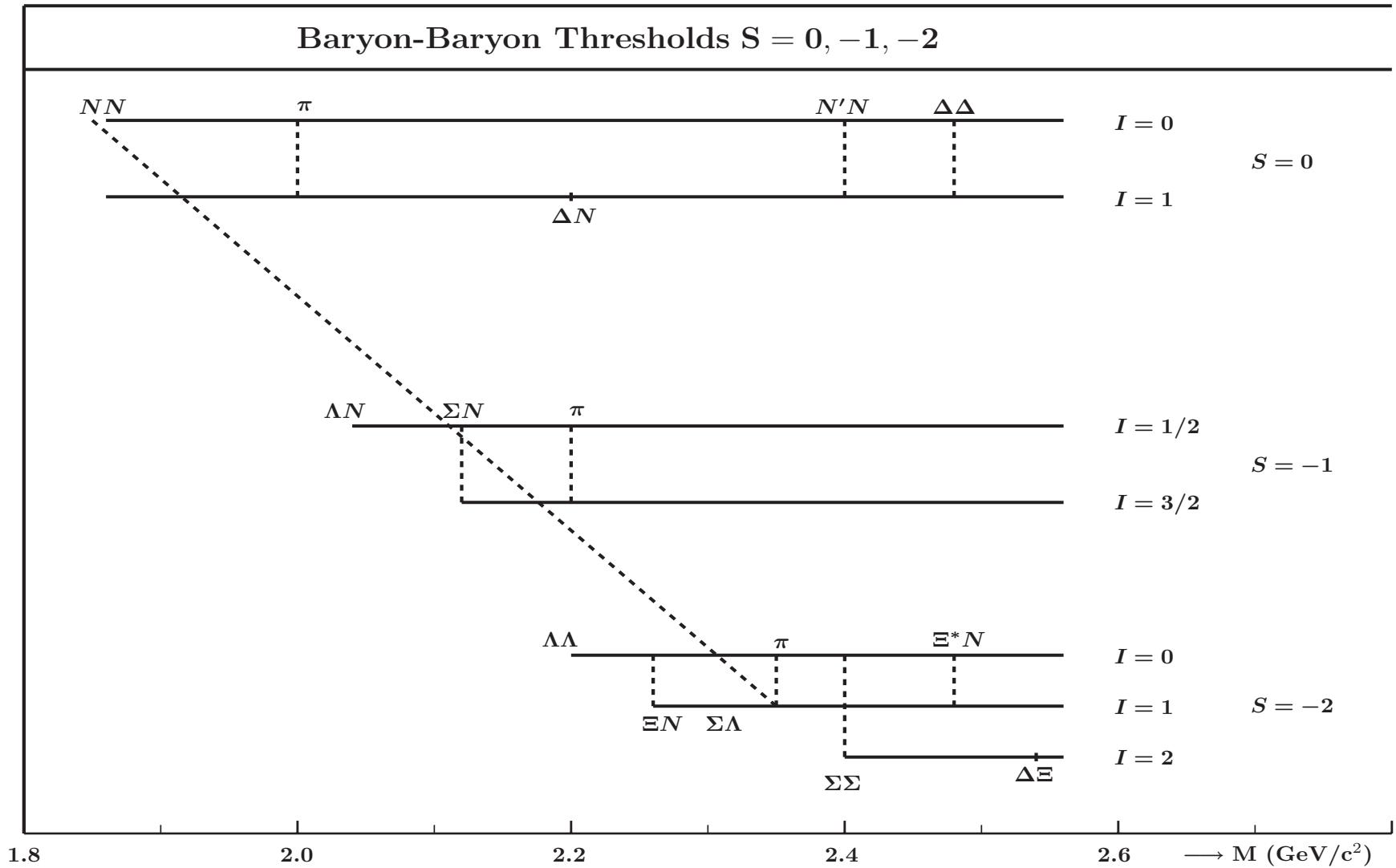
3 Particle and Nuclear Flavor Physics

Particle and Flavor Nuclear Physics

- Objectives in Low/Intermediate Energy Physics:
 1. Study links Hadron-interactions and Quark-physics (QCD, QPC)
 2. Construction realistic physical picture of nuclear forces between the octet-baryons: N, Λ, Σ, Ξ
 3. Study (broken) $SU_F(3)$ -symmetry
 4. Determination Meson Coupling Parameters \Leftarrow NN+YN Scattering
 5. Analysis and interpretation experimental scattering data, and (hyper) nuclei-data
 6. Basis nuclear-model and nuclear-matter studies, TBF
 7. CERN, KEK, TJNAL, FINUDA, JPARC(2012), FAIR, RHIC
 8. Extension to nuclear systems with c-, b-, t-quarks

4 Baryon-baryon Channels $S = 0, -1, -2$

BB: The baryon-baryon channels $S = 0, -1, -2$



5 SU(3)-Symmetry Hadronen, BB-channels

Baryon-Baryon Interactions: SU(3)-Flavor Symmetry

- **Quark Level:** $SU(3)_{flavor} \Leftrightarrow$ Quark Substitutional Symmetry (!!)]
'gluons are flavor blind'
- $p \sim UUD$, $n \sim UDD$, $\Lambda \sim UDS$, $\Sigma^+ \sim UUS$, $\Xi^0 \sim USS$
- **Mass differences** \Leftrightarrow Broken $SU(3)_{flavor}$ symmetry
- Baryon-Baryon Channels:

NN	: pp	,	np	,	nn	$S = 0$
YN	: $\Sigma^+ p$,	$\Sigma^- p \rightarrow \Sigma^- p, \Sigma^0 n, \Lambda n$,	$\Lambda p \rightarrow \Lambda p, \Sigma^+ n, \Sigma^0 p$	$S = -1$
ΞN	: $\Xi^0 p$,	$\Xi N \rightarrow \Xi^- p, \Lambda \Lambda, \Sigma \Sigma$			$S = -2$
ΞY	:	,	$\Xi \Lambda \rightarrow \Xi \Lambda, \Xi \Sigma$			$S = -3$
$\Xi \Xi$: $\Xi^0 \Xi^0$,	$\Xi^0 \Xi^-$			$S = -4$

- SU(3) classification BB-channels:

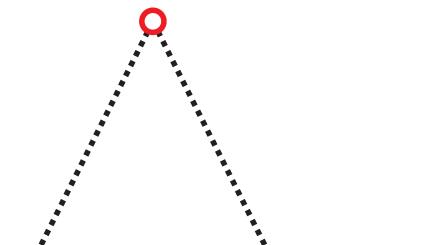
$$\{8\} \otimes \{8\} = \{27\} \oplus \{10\} \oplus \{10^*\} \oplus \{8_s\} \oplus \{8_a\} \oplus \{1\}$$

6 SU(3)-Symmetry Hadronen, BB-decuplet !!

Baryon-Baryon Decuplet-states $\{10^*\}$, $^{2s+1}L_J = {}^3S_1, {}^1P_1, {}^3D, \dots$

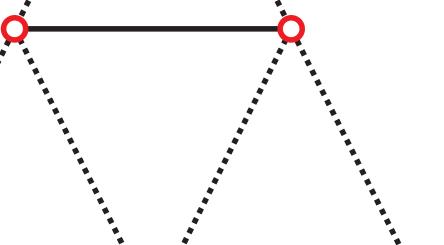
$Y = 2, S = 0$

$np(I = 0)$, deuteron



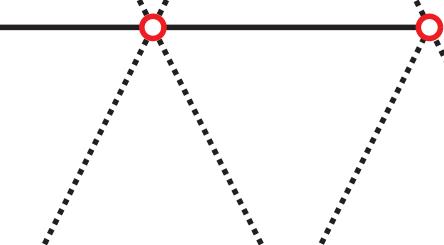
$Y = 1, S = -1$

$\Lambda N, \Sigma N (I = 1/2)$



$Y = 0, S = -2$

$\Xi N, \Lambda \Sigma, \Sigma \Sigma (I = 1)$



$Y = -1, S = -3$

$\Xi \Sigma (I = 3/2)$



7 Introduction: Competing BB-models

Theory Interest in Flavor Nuclear Physics

- Recent Model building:
 1. Nijmegen models: OBE and ESC Soft-core (SC)
[Rijken, Phys.Rev. C73, 044007 \(2006\)](#)
[Rijken & Yamamoto, Phys.Rev. C73, 044008 \(2006\)](#)
 2. Chiral-Unitary Approach model
[Sasaki, Oset, and Vacas, Phys.Rev. C74, 064002 \(2006\)](#)
 3. Jülich Meson-exchange models
[Haidenbauer, Meissner, Phys.Rev. C72, 044005 \(2005\)](#)
 4. Bochum/Jülich Effective Field Theory models
[Epelbaum, Polinder, Haidenbauer, Meissner](#)
 5. Quark-Cluster-models: QGE + RGM
[Fujiwara et al, Progress in Part. & Nucl.Phys. 58, 439 \(2007\)](#)
[Valcarce et al, Rep.Progr.Phys. 68, 965 \(2005\)](#)
 6. Lattice Computations: Nemura,

8 Role BB-interaction Models

Particle and Flavor Nuclear Physics

- Concepts:

QCD: Colored quarks + gluons

Confinement $SU_c(3)$

Strong coupling $g_{QCD} \approx 1$

Lattice QCD: flux-tubes/strings

Flavor SU_f -symmetry

Spontaneous CSB

Principle: "Experientia ac ratione"

(Christiaan Huijgens 1629-1695)

- Experiments:

NN-scattering

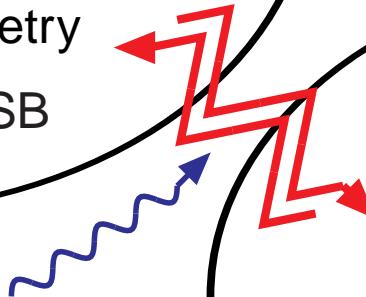
YN- & YY-scattering

Nuclei & Hypernuclei

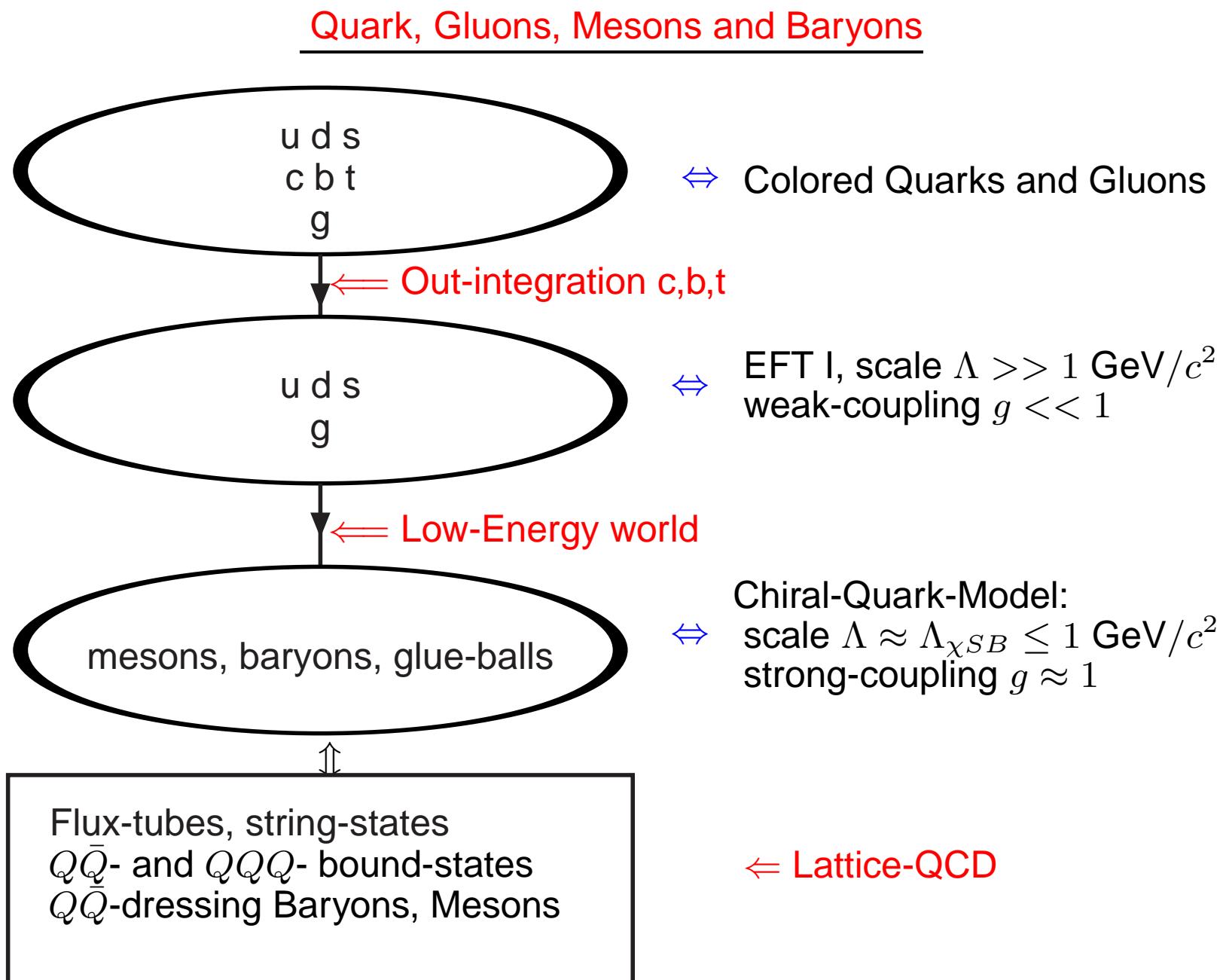
Nuclear- & Hyperonic matter

Neutron-star matter

BB-interaction
models



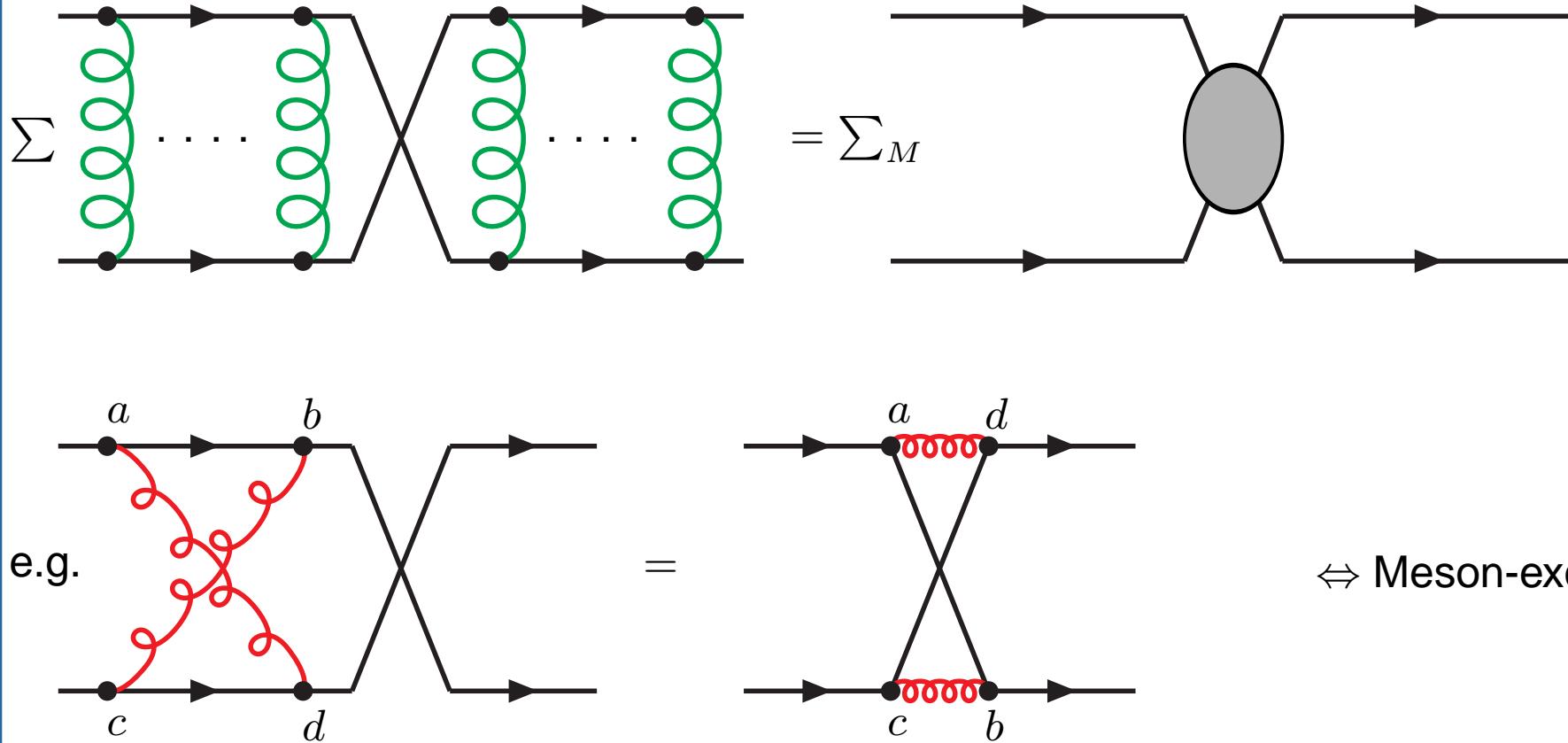
9 QCD-world



11 Gluon-Quark-Exchange

Gluon-Quark-Exchange \leftrightarrow Meson-Exchange

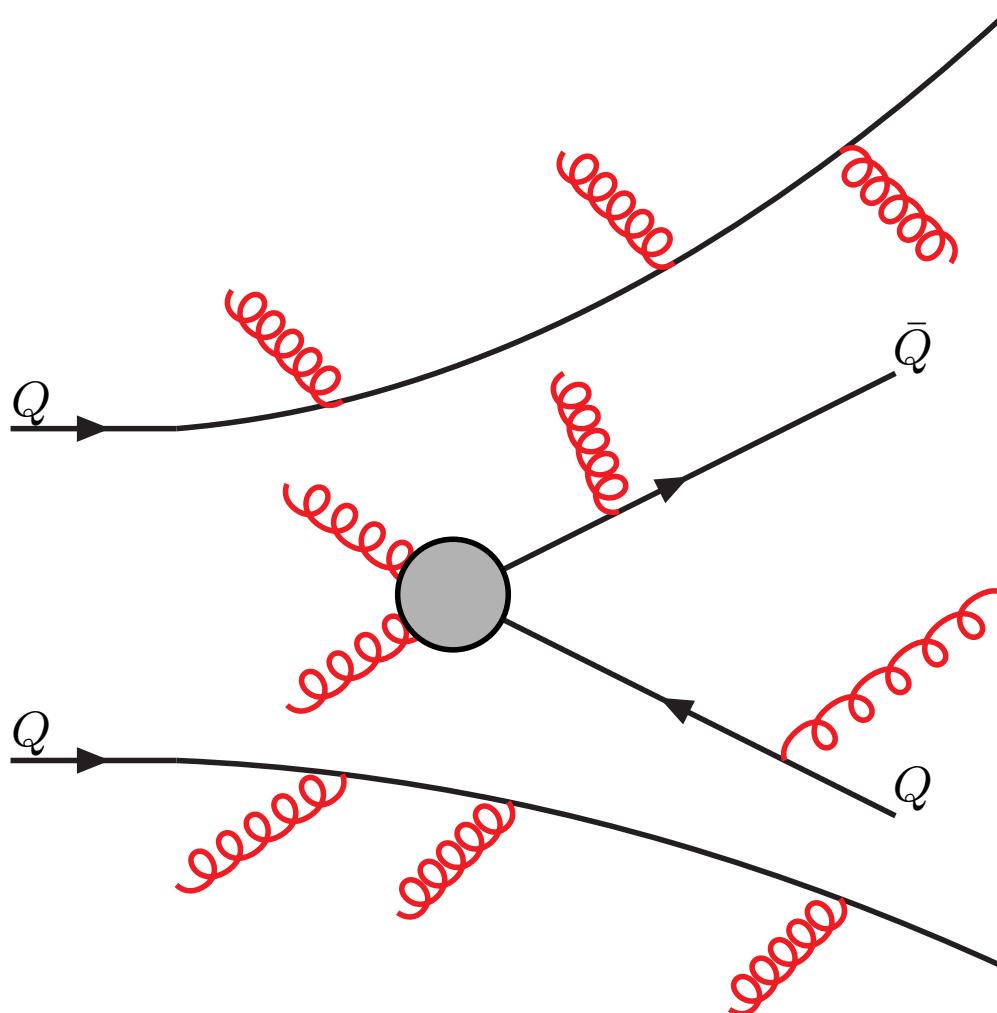
- Strong-coupling regime QQ-interaction: Quark-, Multi-gluon-exchange



12 Quark-Pair-Creation in QCD

Quark-Pair-Creation in QCD \Leftrightarrow Flux-tube breaking

- Strong-coupling regime QQ-interaction: Multi-gluon exchange



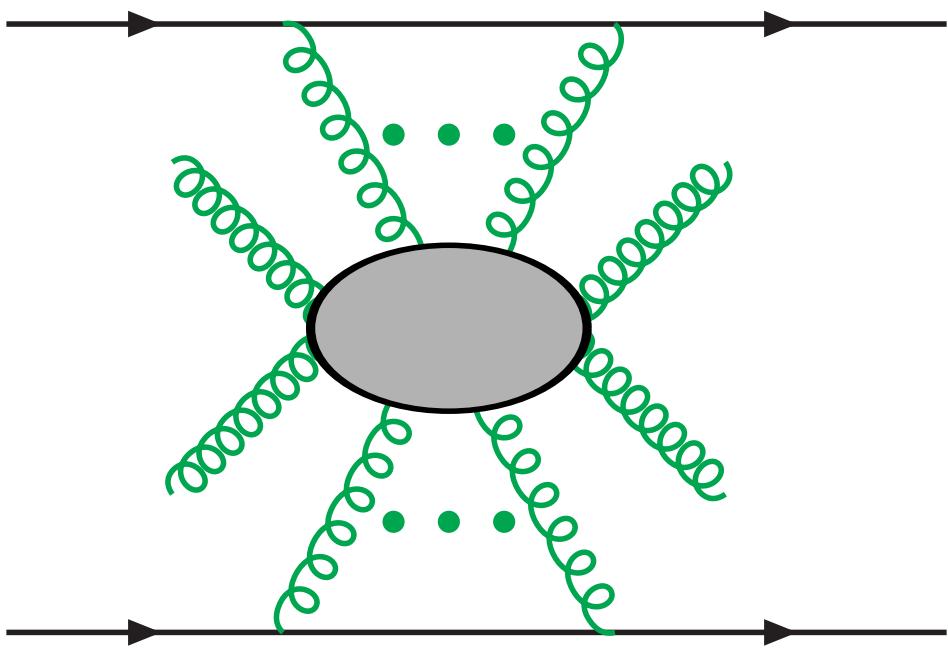
QPC: 3P_0 -dominance:
Micu, NP B10(1969);
Carlitz & Kislinger, PR D2(1970),
LeYaounanc et al, PR D8(1973).

QCD: Flux-tube/String-breaking
 $\Rightarrow ^3P_0(Q\bar{Q})$ (!),
Isgur & Paton, PRD31(1985);
Kokoski & Isgur, PRD35(1987)

13 Gluon-exchange \leftrightarrow Pomeron

Multiple Gluon-exchange QCD \leftrightarrow Pomeron/Odderon

- Gluon-exchange \leftrightarrow Pomeron-exchange



Multiple-gluon model: Low PR D12(1975),
Nussinov PRL34(1975)

Scalar Gluon-condensate: ITEP-school:
 $\langle 0 | g^2 G_{\mu\nu}^a(0) G^{a\mu\nu}(0) | 0 \rangle = \Lambda_c^4,$
 $\Lambda_c \approx 800 \text{ MeV}$

Landshoff, Nachtmann, Donnachie,
Z.Phys.C35(1987); NP B311(1988):

$\langle 0 | g^2 T[G_{\mu\nu}^a(x) G^{a\mu\nu}(0)] | 0 \rangle =$
 $\Lambda_c^4 f(x^2/a^2), a \approx 0.2 - 0.3 \text{ fm}$

Triple-Pomeron: $g_{3P}/g_P \sim 0.15 - 0.20$,
Kaidalov & T-Materosyan, NP B75 (1974)

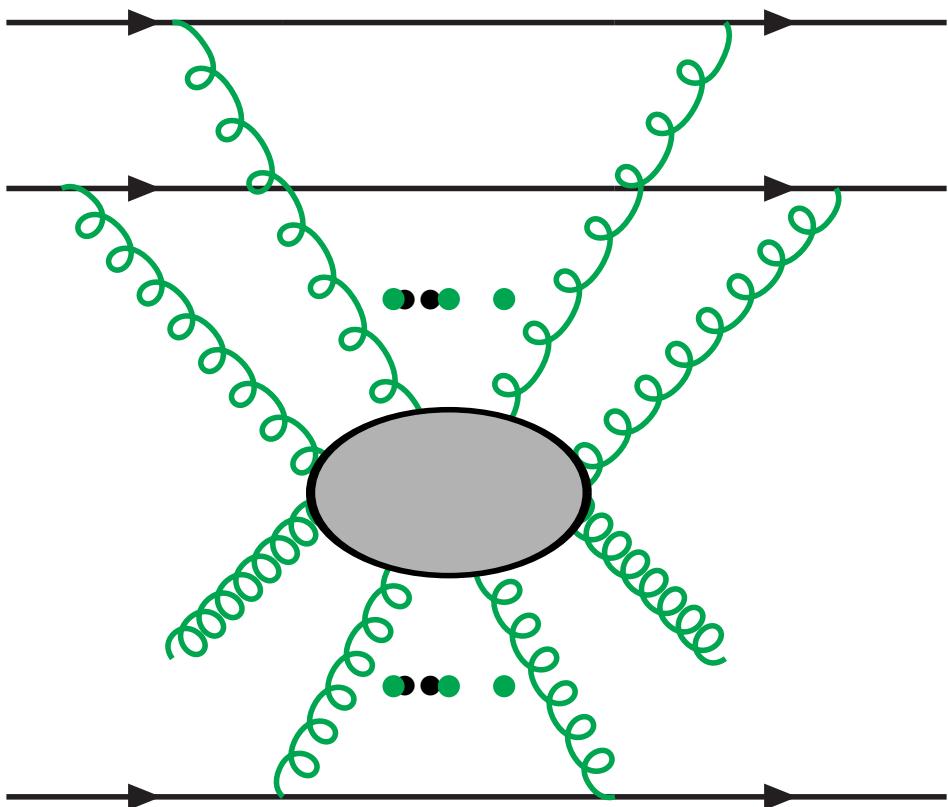
Quartic-Pomeron: $g_{4P}/g_P \sim 4.5$,
Bronzan & Sugar, PRD 16 (1977)

- Two/Even-gluon exchange \leftrightarrow Pomeron
- Three/Odd-gluon exchange \leftrightarrow Odderon

14 Universal Three-body repulsion \Leftrightarrow Pomeron

Universal Three-body repulsion \Leftrightarrow Pomeron-exchange

- Multiple Gluon-exchange \Leftrightarrow Pomeron-exchange



Soft-core models NSC97, ESC04/08:
(i) nuclear saturation, (ii) EOS too soft
Nishizaki, Takatsuka, Yamamoto,
PTP 105(2001); ibid 108(2002): NTY-
conjecture = universal repulsion in BB

Lagaris-Pandharipande NP A359(1981):
medium effect \rightarrow TNIA, TNIR
Rijken-Yamamoto PRC73: TNR $\Leftrightarrow m_V(\rho)$

TNIA \Leftrightarrow Fujita-Miyazawa (Yamamoto)

TNIR \Leftrightarrow Multiple-gluon-exchange \Leftrightarrow
Triple-Pomeron-model (TAR 2007)
String-Junction-model (Tamagaki 2007)

15 ‘Six-Quark-core Effects I

Six-Quark-Core Effect: Forbidden States

- Idea's in P.T.P. in Sixties (!), Sakata-model inspired:

'Origin related to internal structure baryons'

1. S.Otsuki, R.Tamagaki, and W.Wada, P.T.P **32** (1964) 320
2. S.Otsuki, R.Tamagaki, and M.Yasuno, P.T.P Suppl. 1965
3. M.Sato and R.Tamagaki, P.T.P **37** (1965) 1147
4. R.Tamagaki and H.Tanaka, P.T.P **34** (1965) 191,
analogy with $\alpha - \alpha$ repulsive core.

16 Six-Quark-core Effects II

Six-Quark-Core Effect: Forbidden States

- Irreps [51], [33] of $SU(6)_{fs}$ and the Pauli-principle
- $SU(3)_f$ -irreps $\{27\}, \{10^*\}$, etc. in terms of the $SU(6)_{fs}$ -irreps:

$$V_{\{27\}} = \frac{4}{9}V_{[51]} + \frac{5}{9}V_{[33]}, \quad (1a)$$

$$V_{\{10^*\}} = \frac{4}{9}V_{[51]} + \frac{5}{9}V_{[33]}, \quad (1b)$$

$$V_{\{10\}} = \frac{8}{9}V_{[51]} + \frac{1}{9}V_{[33]}, \quad (1c)$$

$$V_{\{8_a\}} = \frac{5}{9}V_{[51]} + \frac{4}{9}V_{[33]}, \quad (1d)$$

$$V_{\{8_s\}} = V_{[51]}, \quad V_{\{1\}} = V_{[33]}. \quad (1e)$$

Forbidden irrep [51] has large weight in $\{10\}$ and $\{8_s\}$ ->
Adaption Pomeron strength for these irreps.

- Pomeron \Leftrightarrow Multi-gluon Exch. + Quark-core effect !
- Literature: P.T.P. Suppl. 137 (2000), Oka et al

17 Short-range Phenomenology-1

- Corollary:

We have seen that the [51]-irrep has a large weight in the {10}- and {8_s} -irrep, which gives an argument for the presence of a strong Pauli-repulsion in these $SU(3)_f$ -irreps \Rightarrow

ESC08: implementation by adapting the Pomeron strength
in BB-channels.

- Repulsive short-range potentials:

$$V_{BB}(SR) = V(POM) + V_{BB}(PB), \quad V_{NN}(PB) \equiv V_P$$

$$ESC08c: \text{ linear form} \Rightarrow V_{BB}(PB) = (w_{BB}[51]/w_{NN}[51]) \cdot V_{NN}(PB)$$

$$ESC08c': \text{ tangential} \Rightarrow V_{BB}(PB) = \tan(\varphi_{BB}) \cdot V_{NN}(PB),$$

$$\bullet \varphi_{BB} = \left(\frac{w_{BB}[51] - w_{NN}[51]}{w_{10}[51] - w_{NN}[51]} \right) \cdot (\varphi_{max} - \varphi_{min}) + \varphi_{NN}.$$

$$\bullet \varphi_{NN} = \varphi_{min} = 45^\circ, \quad \varphi_{max} = \varphi_{10}, \quad \arctan(\varphi_{max}) = 2.$$

Short-range Phenomenology-2

- ESC08c:

BB	(S,I)	a_{PB}
NN	(0,1) (1,0)	1.0
ΛN	(0,1/2) (1,1/2)	1.02
ΣN	(0,1/2)	1.17
	(1,1/2)	1.02
	(0,3/2)	1.0
	(1,3/2)	1.15
ΞN	(0,0)	0.96
	(0,1)	1.12
	(1,0)	1.04
	(1,1)	1.06

Almost Pauli-forbidden states [51]:
linear parametrization S.R. repulsion

$$\begin{aligned}V_{NN} &= (1 - a_{PB})V_P + a_{PB}V_P \\&\equiv V(POM) + V_{NN}(PB), \\V_{BB}(PB) &= (w_{BB}[51]/w_{NN}[51]) \cdot V_{NN}(PB).\end{aligned}$$

18 Methodology ESC08-model Analysis

Strategy: Combined Analysis NN -, YN -, and YY -data

Input data/pseudo-data:

- NN-data : 4300 scattering data + low-energy par's
- YN-data : 52 scattering data
- Nuclei/hyper-nuclei data: BE's Deuteron, well-depth's $U_\Lambda, U_\Sigma, U_\Xi$
- Hadron physics: experiments + theory
 - a) Flavor SU(3), (b) Quark-model, (c) QCD \leftrightarrow gluon dynamics
- "Venutian-approach"(Feynman): 4x9=36 Meson-fields: Yukawa-forces + Short range forces (gluon-exchange/Pomeron/Odderon, Pauli-repulsion)

Output: ESC08-models (2011, 2012)

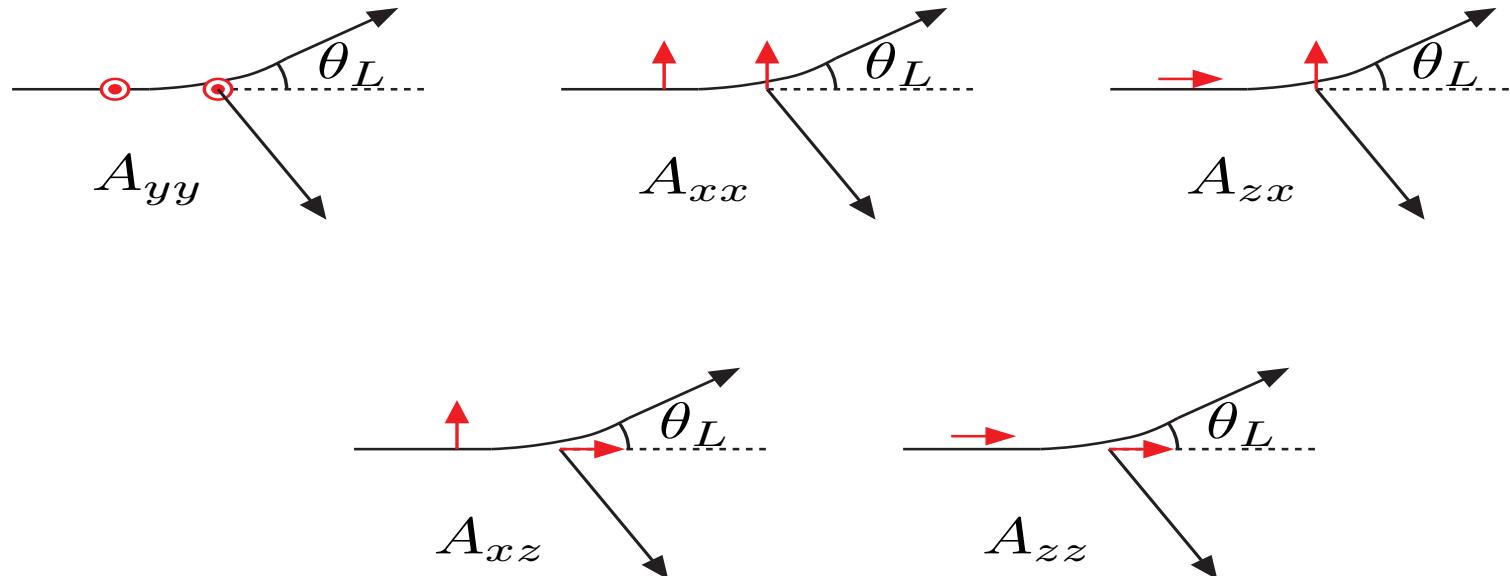
- Fit NN-data $\chi^2_{p.d.p.} = 1.08$ (!), deuteron, YN-data $\chi^2_{p.d.p.} = 1.00$
- Description all well-depth's, NO S=-1 bound-states (!), small Λp spin-orbit (Tamura), $\Delta B_{\Lambda\Lambda}$ a la Nagara (!)

Predictions: (a) Deuteron $D(Y = 0)$ -state in $\Xi N(I = 1, ^3 S_1)$ (!??), (b) Deuteron $D(Y = -2)$ -state in $\Xi\Xi(I = 1, ^1 S_0)$ (!??)

- Predictions model-dependent: Need more precise $\Sigma^+ P-$, $\Lambda p-$, $\Xi N-$ info!!!

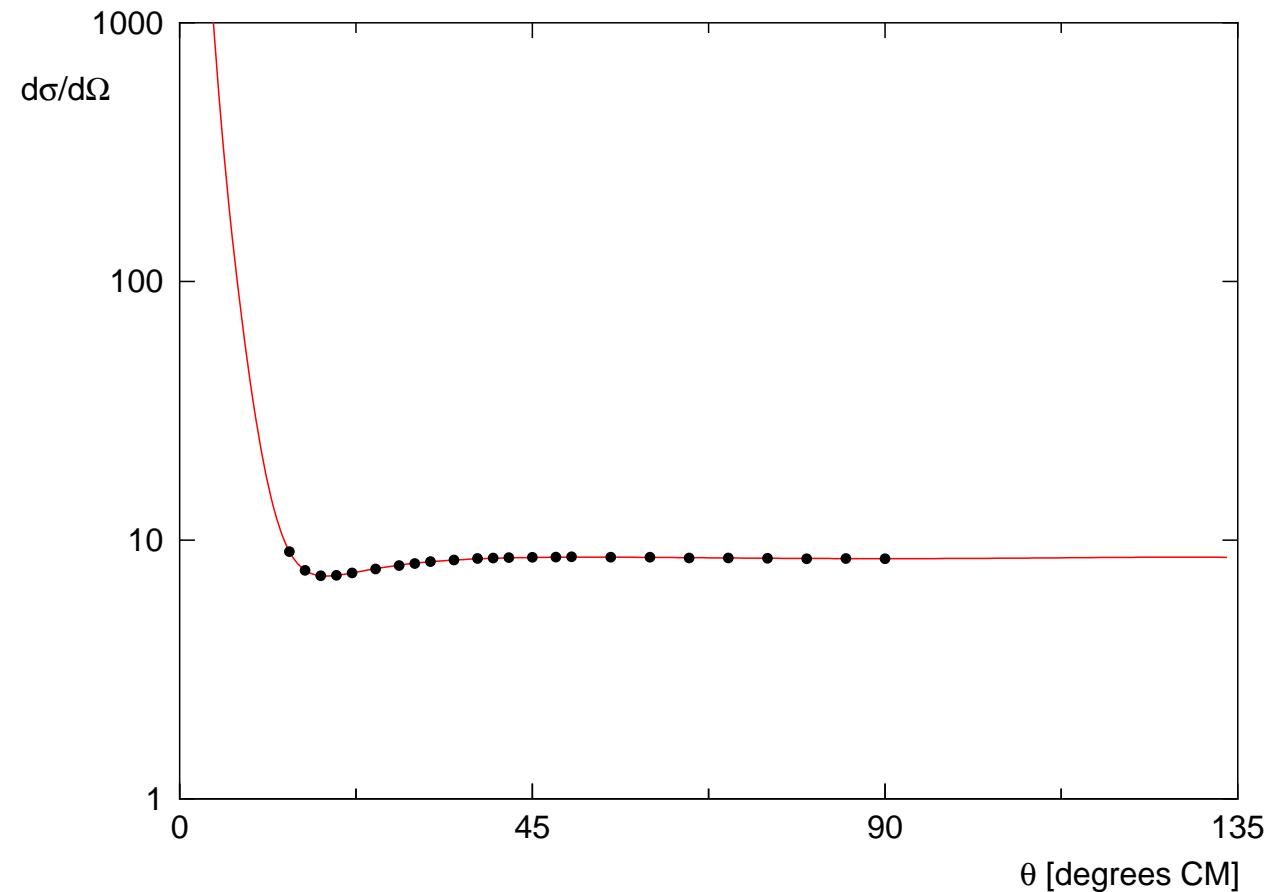
19 Spin-correlation parameters

Spin-correlation parameters A_{yy} , A_{xx} , A_{zx} , A_{xz} , and A_{zz} .



Spin-correlation parameters A_{yy} , A_{xx} , A_{zx} , A_{xz} , and A_{zz} .

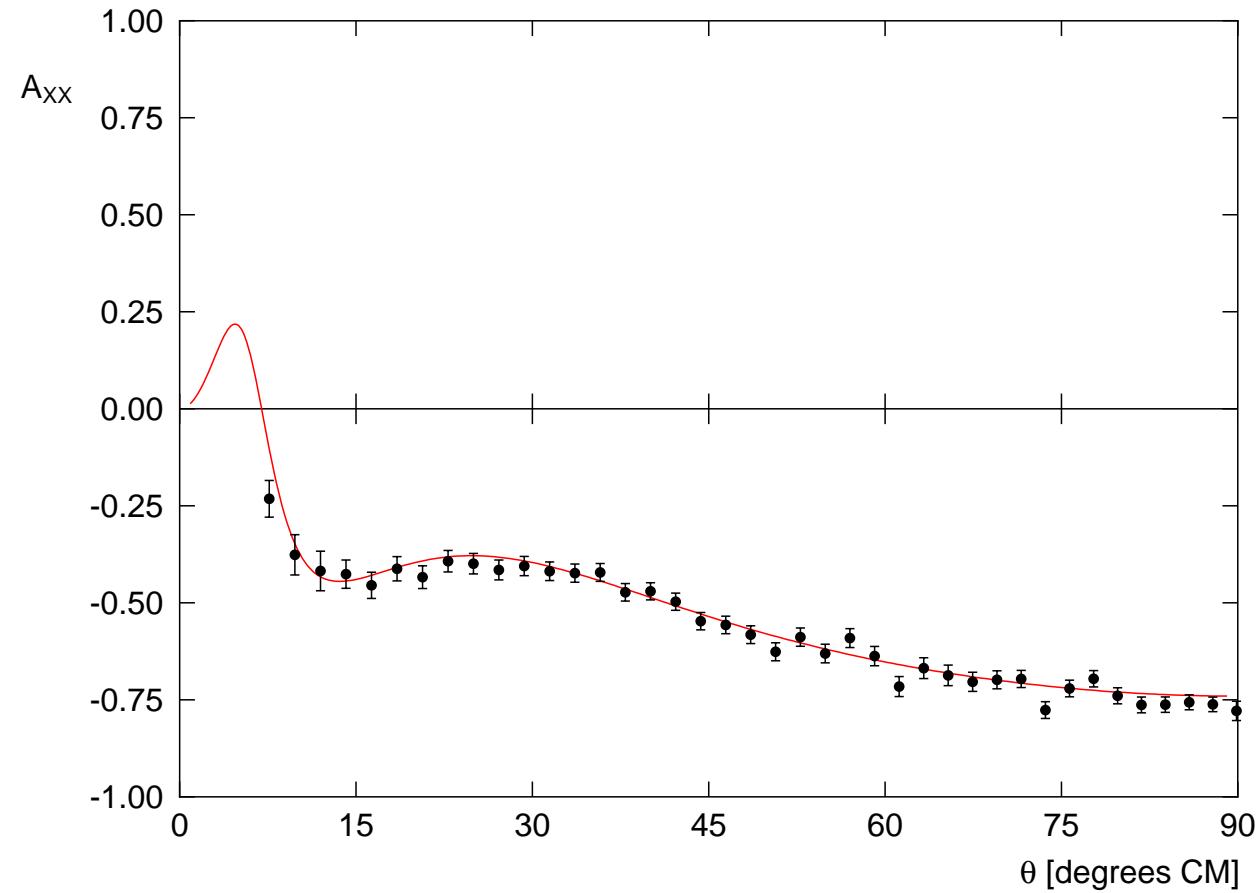
20 PWA-93, 1



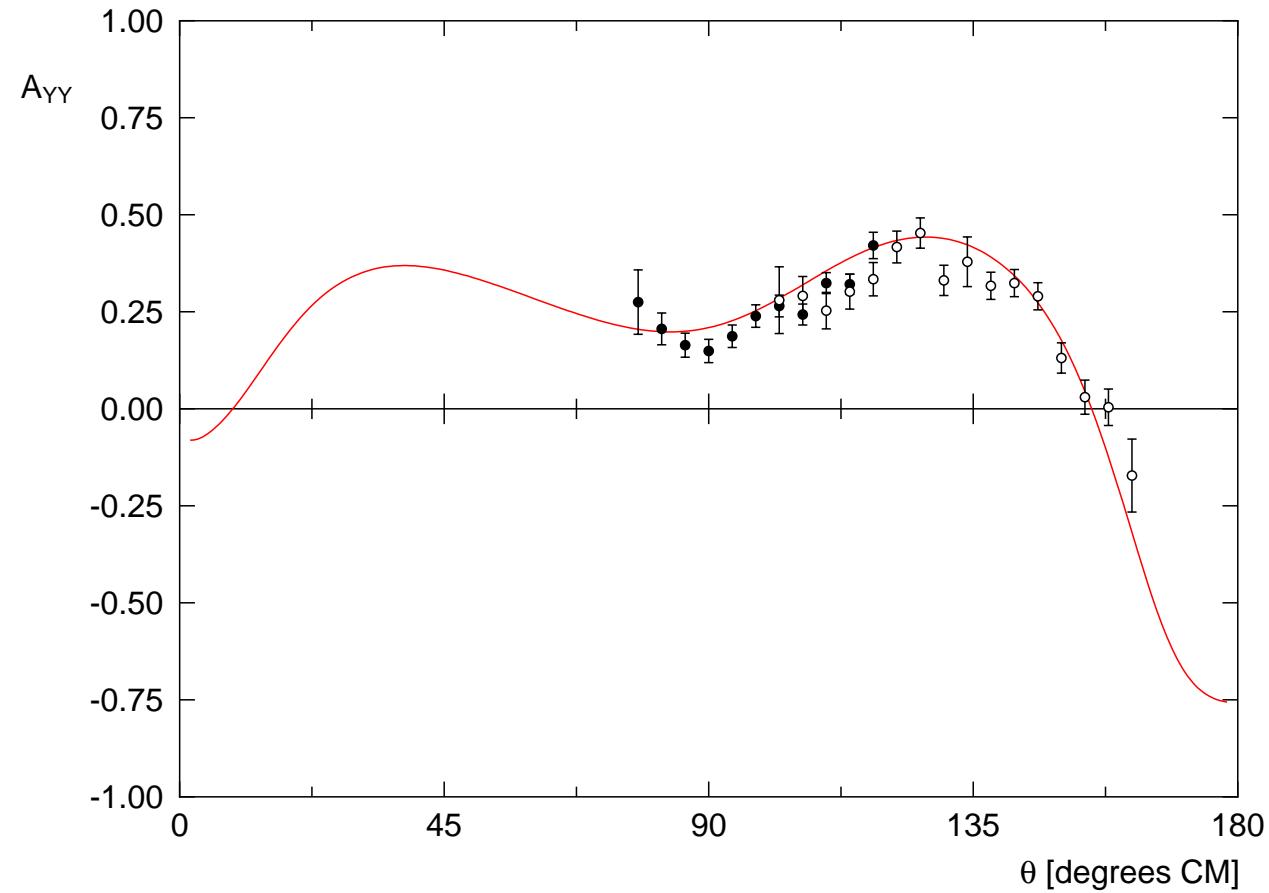
pp observable $d\sigma/d\Omega$ at $T_{lab} = 50.06$ MeV

— PWA93

• Berdoz et al., SIN(1986)



22 PWA-93, 3



np observable A_{YY} at T_{lab} = 315.0 MeV

23 ESC-model,dynamical contents

ESC08c: Soft-core $NN + YN + YY$ ESC-model

- extended ESC04-model, PRC73 (2006)
- NN: 20 free parameters: couplings, cut-off's, meson mixing and F/(F+D)-ratio's
- meson nonets:

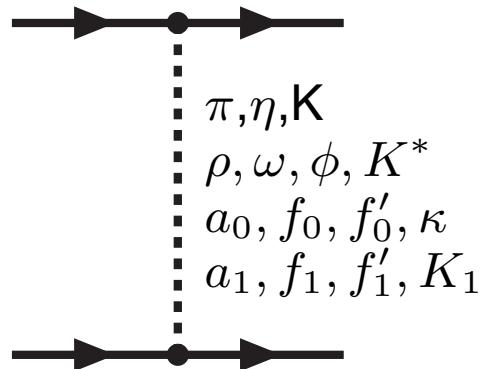
$$\begin{aligned} J^{PC} = 0^{-+}: \quad & \pi, \eta, \eta', K \quad ; = 1^{--}: \quad \rho, \omega, \phi, K^* \\ = 0^{++}: \quad & a_0(962), f_0(760), f_0(993), \kappa_1(900) \\ = 1^{++}: \quad & a_1(1270), f_1(1285), f_0(1460), K_a(1430) \\ = 1^{+-}: \quad & b_1(1235), h_1(1170), h_1(1380), K_b(1430) \end{aligned}$$

- soft TPS: two-pseudo-scalar exchanges,
- soft MPE: meson-pair exchanges: $\pi \otimes \pi, \pi \otimes \rho, \pi \otimes \epsilon, \pi \otimes \omega$, etc.
- pomeron/odderon exchange \Leftrightarrow multi-gluon / pion exchange
- quark-core effects,
- gaussian form factors, $\exp(-\mathbf{k}^2/2\Lambda_{B'BM}^2)$
- Simultaneous NN+YN Data (constrained) fit, 4301 NN-data, 52 YN-data:
 1. Nucleon-nucleon: pp + np, $\chi^2_{dpt} = 1.08(!)$
 2. Hyperon-nucleon: $\Lambda p + \Sigma^\pm p$, $\chi^2_{dpt} \approx 1.00$

24 ESC-model: OBE+TME

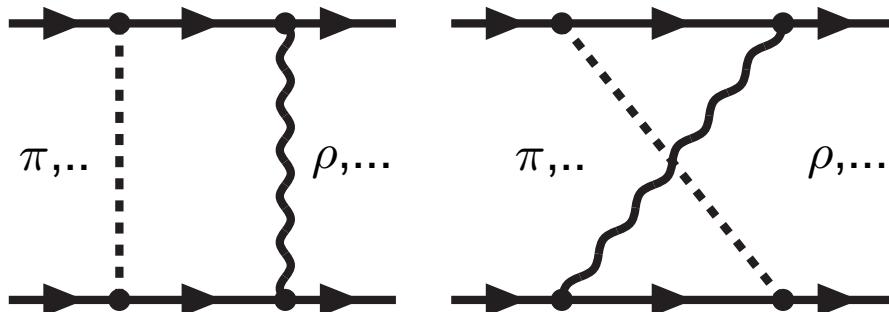
BB-interactions in the ESC-model:

One-Boson-Exchanges:



pseudo-scalar	π	K	η	η'
vector	ρ	K^*	ϕ	ω
axial-vector	a_1	K_1	f'_1	f_1
scalar	δ	κ	S^*	ϵ
diffractive	A_2	K^{**}	f	P

Two-Meson-Exchanges:

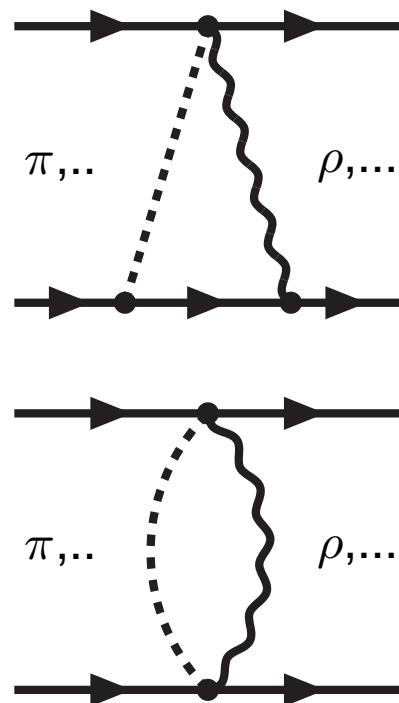


$$\begin{pmatrix} \pi \\ K \\ \eta \\ \eta' \end{pmatrix} \otimes \left\{ \begin{array}{lcl} \pi & K & \eta \quad \eta' \\ \rho & K^* & \phi \quad \omega \\ a_1 & K_1 & f_1 \quad f'_1 \\ \delta & \kappa & S^* \quad \epsilon \\ A_2 & K^{**} & f \quad P \end{array} \right\}$$

25 ESC-model: Meson-Pair exchanges

BB-interactions in the ESC-model (cont.):

Meson-Pair-Exchanges:



$PP\hat{S}_{\{1\}}$: $\pi\pi, K\bar{K}, \eta\eta$

$PP\hat{S}_{\{8\}_s}$: $\pi\eta, K\bar{K}, \pi\pi, \eta\eta$

$PP\hat{V}_{\{8\}_a}$: $\pi\pi, K\bar{K}, \pi K, \eta K$

$PV\hat{A}_{\{8\}_a}$: $\pi\rho, K K^*, K\rho, \dots$

$PS\hat{A}_{\{8\}}$: $\pi\sigma, K\sigma, \eta\sigma$

26 ESC-model: Computational Methods

Computational Methods

- coupled channel systems:

$NN: pp \rightarrow pp$, and $np \rightarrow np$

YN : a. $\Lambda p \rightarrow \Lambda p, \Sigma^0 p, \Sigma^+ n$

b. $\Sigma^- p \rightarrow \Sigma^- p, \Sigma^0 n, \Lambda n$

c. $\Sigma^+ p \rightarrow \Sigma^+ p$

$YY: \Lambda\Lambda \rightarrow \Lambda\Lambda, \Xi N, \Sigma\Sigma$

- potential forms:

$$\begin{aligned} V(r) = & \left\{ V_C + V_\sigma \underline{\sigma}_1 \cdot \underline{\sigma}_2 + V_T S_{12} + V_{SO} \underline{L} \cdot \underline{S} \right. \\ & \left. + V_{ASO} \frac{1}{2} (\underline{\sigma}_1 - \underline{\sigma}_2) \cdot \underline{L} + V_Q Q_{12} \right\} P \end{aligned}$$

- multi-channel Schrödinger equation: $H\Psi = E\Psi$

$$H = -\frac{1}{2m_{red}} \nabla^2 + V(r) - \left(\nabla^2 \frac{\phi}{2m_{red}} + \frac{\phi}{2m_{red}} \nabla^2 \right) + M$$

27 ESC08-model: coupling constants etc.

YN + YY ESC-model 2011: ESC08c

- Notice: simultaneous NN + YN fit, $\chi^2_{p.d.f.}(NN) = 1.084$ (!)

Coupling constants, $F/(F + D)$ -ratio's, mixing angles

mesons		{1}	{8}	$F/(F + D)$
pseudoscalar	f	0.246	0.268	$\alpha_{PV} = 0.35$
vector	g	3.492	0.729	$\alpha_V^e = 1.00$
	f	-2.111	3.515	$\alpha_V^m = 0.42$
scalar	g	4.246	0.897	$\alpha_S = 1.00$
axial	g	1.232	1.103	$\alpha_A = 0.31$
	f	1.444	-1.551	
pomeron	g	3.624	0.000	$\alpha_D = \dots$

$$\Lambda_P(1) = 944.6, \quad \Lambda_V(1) = 675.1, \quad \Lambda_S(1) = 1165.8, \quad \Lambda_A = 1214.1 \quad (\text{MeV})$$

$$\Lambda_P(0) = 925.5, \quad \Lambda_V(0) = 1109.6, \quad \Lambda_S(0) = 1096.8 \quad (\text{MeV}).$$

$$\theta_P = -13.00^\circ \star), \quad \theta_V = 38.70^\circ \star), \quad \theta_A = +50.0^\circ \star, \quad \theta_S = 35.26^\circ \star$$

$$a_{PV} = 1.0 \quad (!) \quad \text{Scalar/Axial mesons: zero in FF} \quad (!)$$

- Odderon: $g_O = 3.827, f_O = -4.108, m_O = 268.5 \text{ MeV}, \text{Fl51}=1+1.13$

28 ESC08c(NN+YN), details NN-fit

χ^2 -distribution PSA93 and ESC08c-model

T_{lab}	#data	χ_0^2	$\Delta\chi^2$	$\hat{\chi}_0^2$	$\Delta\hat{\chi}^2$
0.383	144	137.55	15.0	0.960	0.104
1	68	38.02	46.7	0.560	0.687
5	103	82.23	11.0	0.800	0.107
10	209	257.99	28.2	1.234	0.097
25	352	272.20	29.3	0.773	0.083
50	572	547.67	72.1	0.957	0.126
100	399	382.45	20.6	0.959	0.052
150	676	673.05	100.6	0.996	0.149
215	756	754.52	134.4	0.998	0.178
320	954	945.38	125.8	0.991	0.132
Total	4233	4091.12	583.7	0.948	0.136

- χ_0^2 : χ^2 PSA93, $\hat{\chi}_0^2$: χ_{pdpt}^2 PSA93,
- The χ^2 -access ESC08c(NN+YN)-model is denoted by $\Delta\chi^2$ and $\hat{\chi}^2$, respectively.

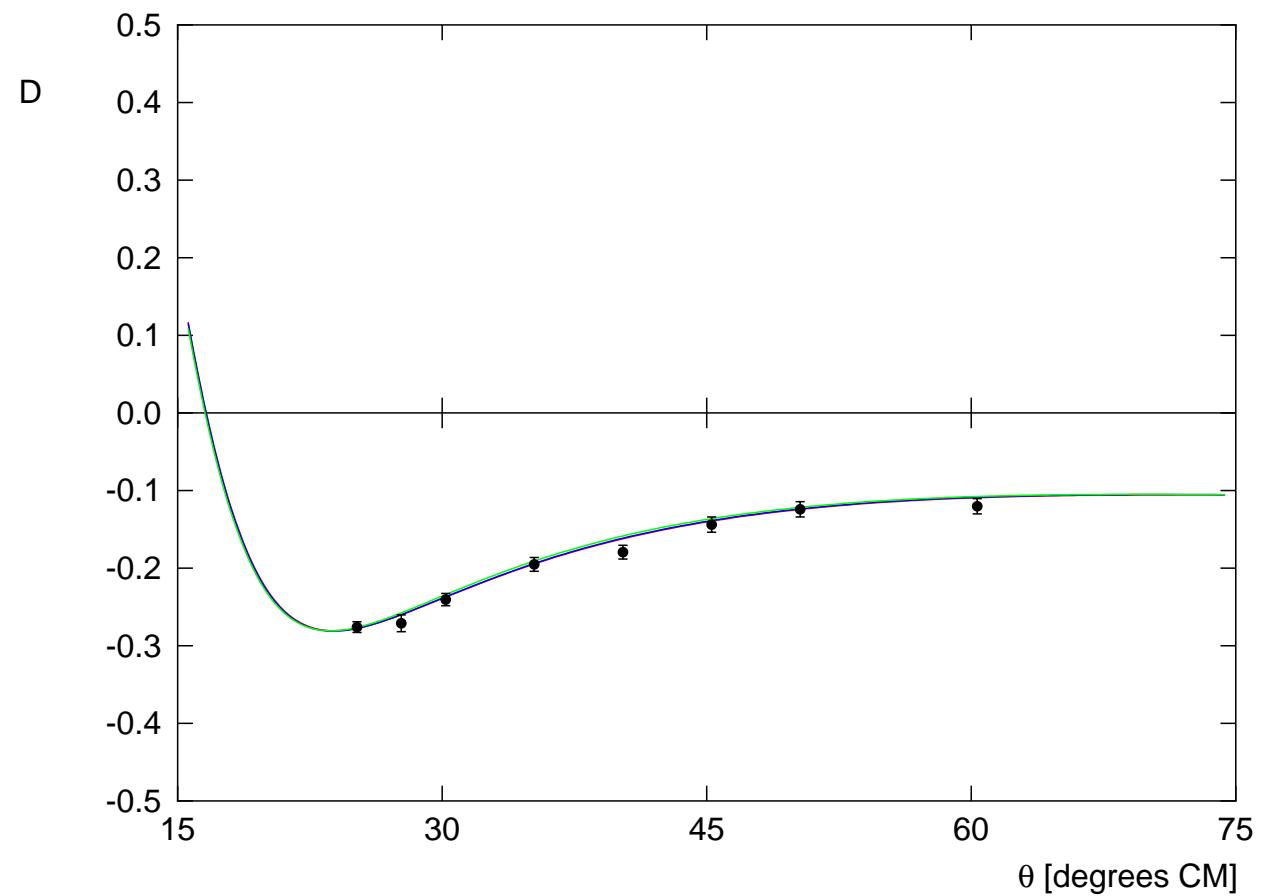
29 ESC08, NN Low-energy parameters

Low energy parameters ESC08c(NN+YN)-model

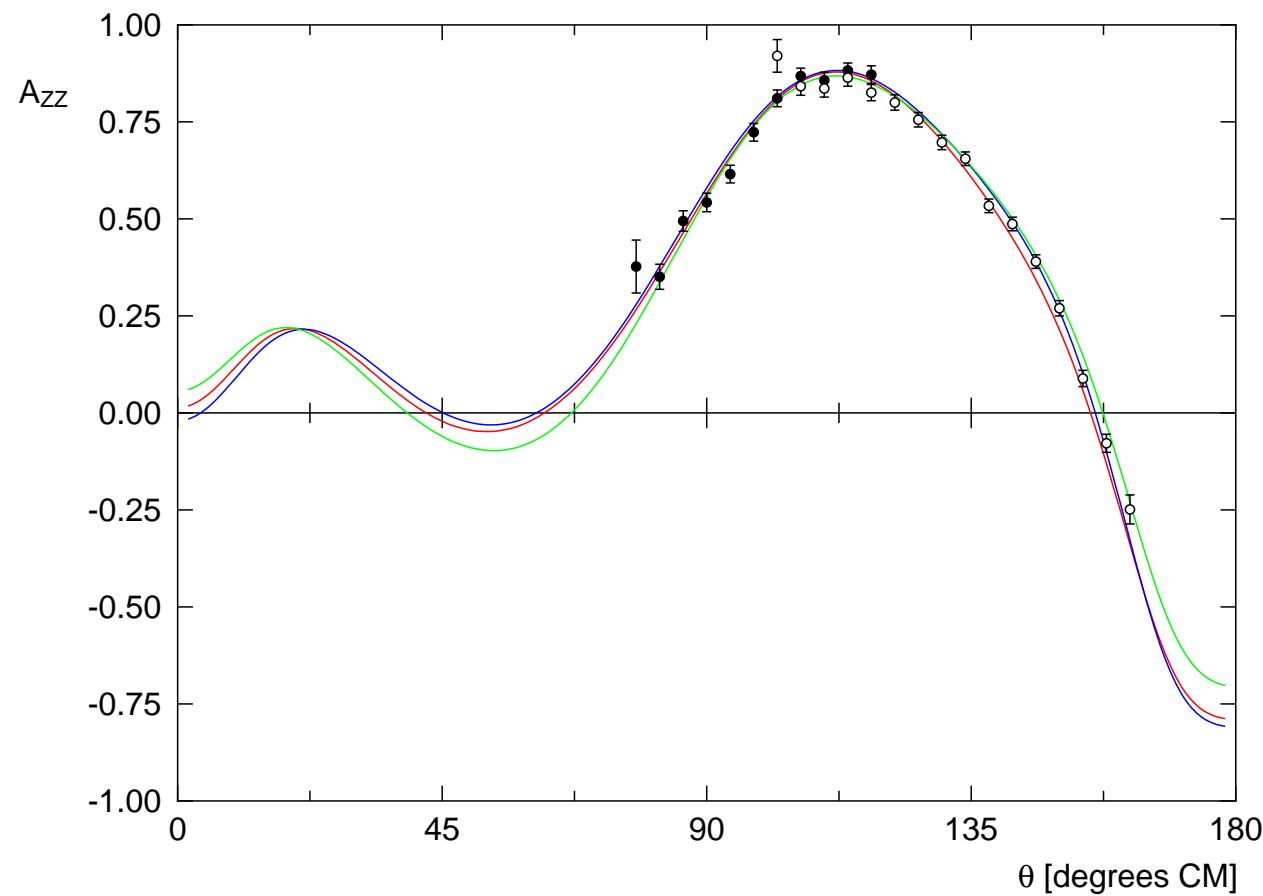
	Experimental data	ESC08b	ESC08c
$a_{pp}(^1S_0)$	-7.823 ± 0.010	-7.772	-7.770
$r_{pp}(^1S_0)$	2.794 ± 0.015	2.751	2.752
$a_{np}(^1S_0)$	-23.715 ± 0.015	-23.739	-23.726
$r_{np}(^1S_0)$	2.760 ± 0.015	2.694	2.691
$a_{nn}(^1S_0)$	-16.40 ± 0.60	-14.91	-15.76
$r_{nn}(^1S_0)$	2.75 ± 0.11	2.89	2.87
$a_{np}(^3S_1)$	5.423 ± 0.005	5.423	5.427
$r_{np}(^3S_1)$	1.761 ± 0.005	1.754	1.752
E_B	-2.224644 ± 0.000046	-2.224678	-2.224621
Q_E	0.286 ± 0.002	0.269	0.270

- Units: [a]=[r]=[fm], $[E_B]$ =[MeV], $[Q_E]$ =[fm] 2 .

30 PWA-93 and ESC, 1



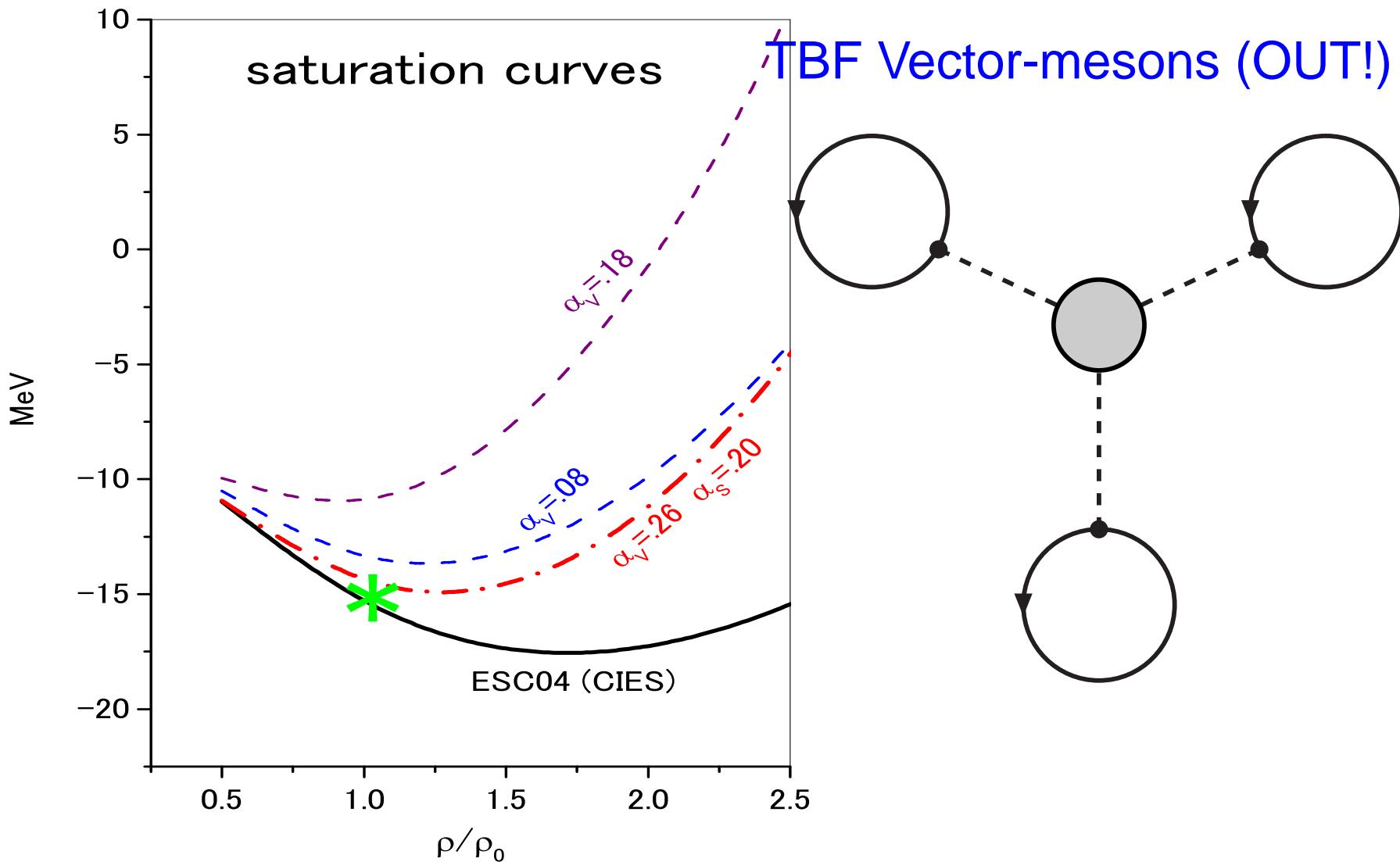
31 PWA-93 and ESC, 2



np observable A_{ZZ} at T_{lab} = 315.0 MeV

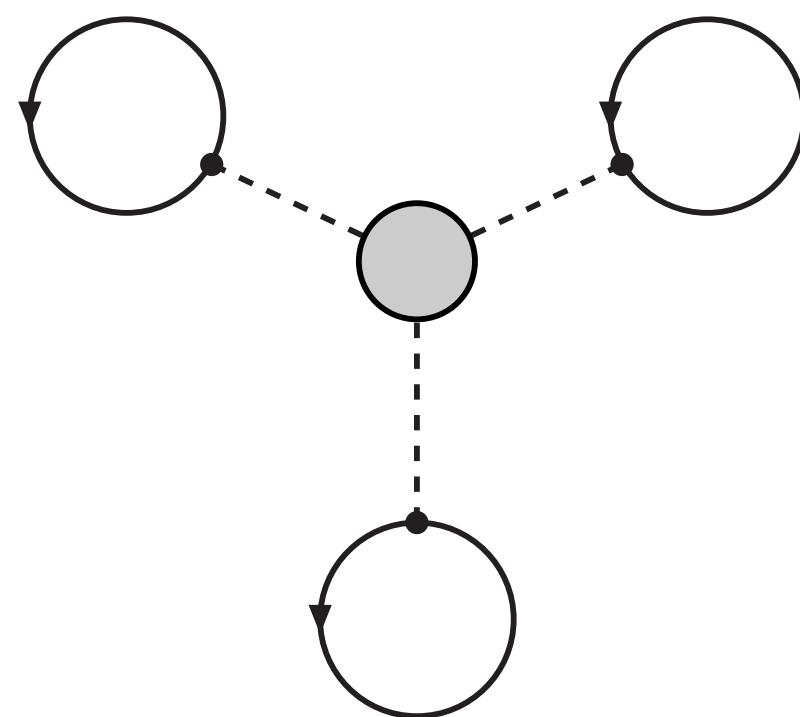
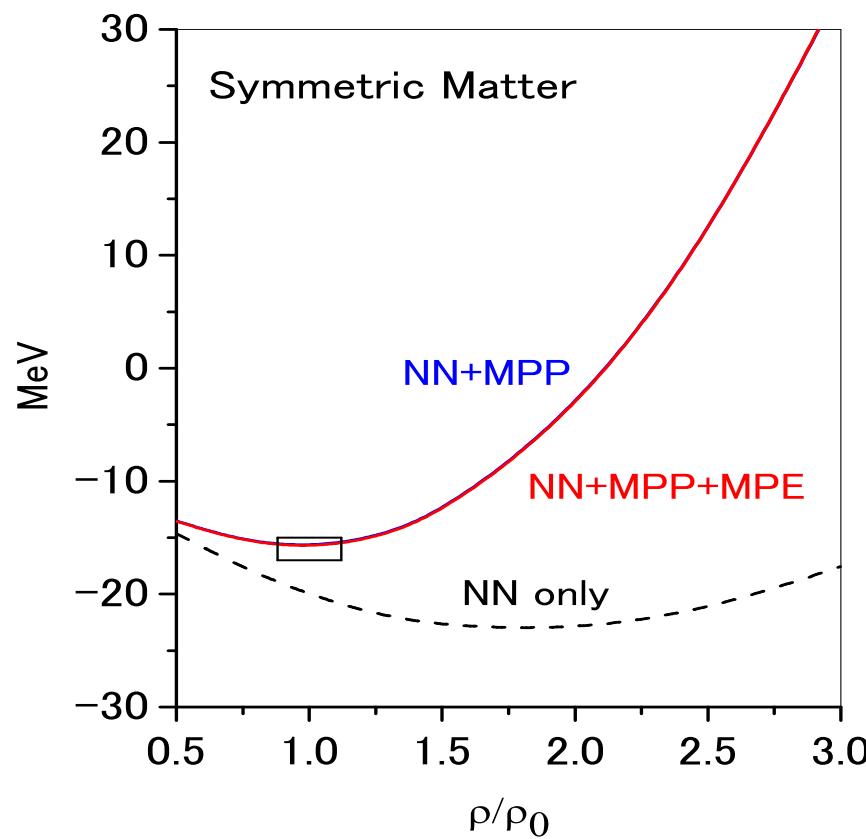
32 Nuclear Matter, Saturation I

ESC04(NN): Binding Energy per Nucleon B/A



ESC08(NN): Binding Energy per Nucleon B/A

Triple-pomeron Repulsion (IN!?)

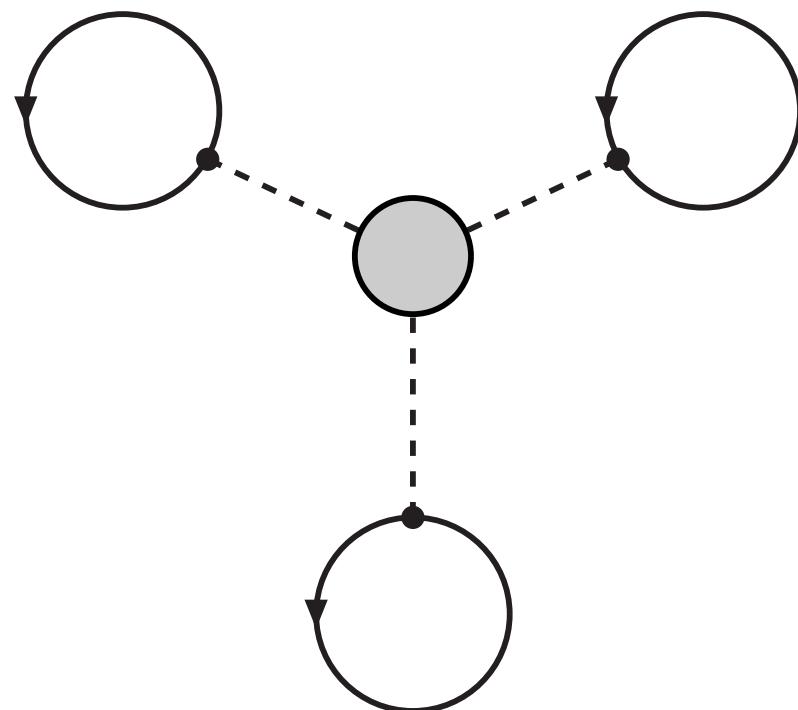
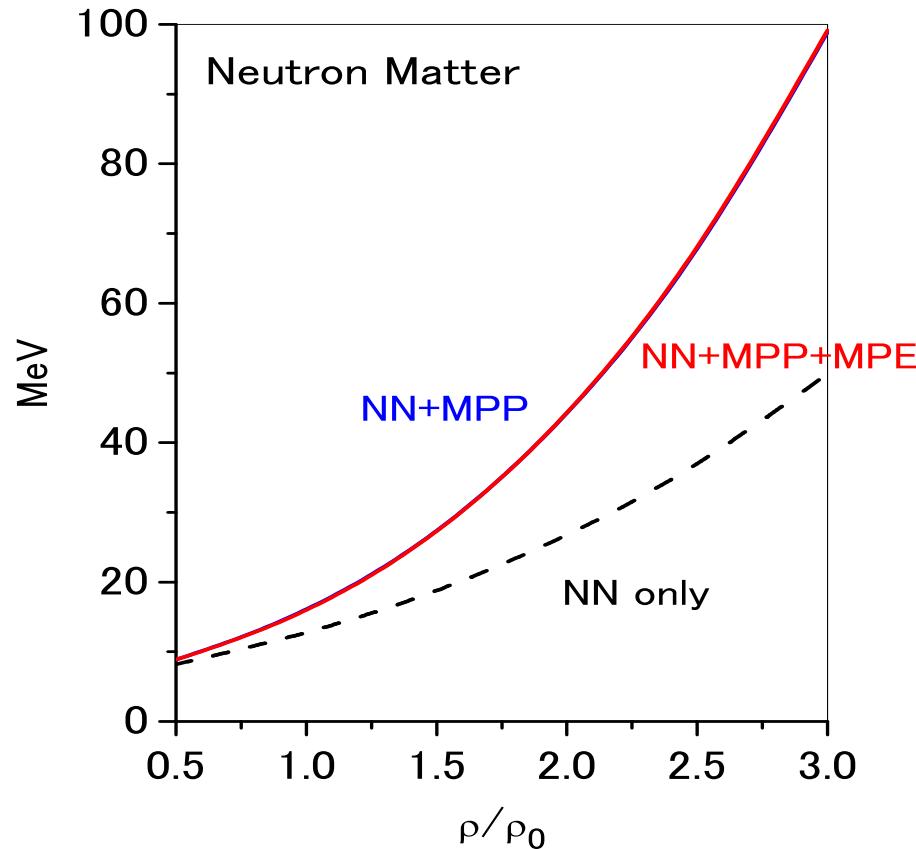


34 ESC08: Nuclear Matter, Saturation III

ESC08(NN): Saturation and Neutron matter

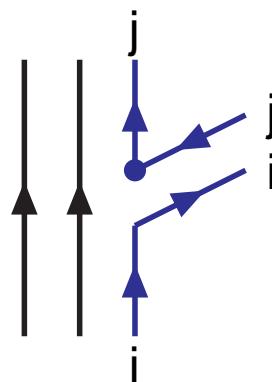
'Exp': $M/M_\odot = 1.44$, $\rho(\text{cen})/\rho_0 = 3 - 4$, $B/A \sim 100 \text{ MeV}$

Schulze-Rijken, PRC84: $M/M_\odot(V_{BB}) \approx 1.35$



35 QPC: 3P_0 -model

Meson-Baryon Couplings from 3P_0 -Mechanism



3P_0 Interaction Lagrangian:

$$\mathcal{L}_I^{(S)} = \gamma \left(\sum_j \bar{q}_j q_j \right) \cdot \left(\sum_i \bar{q}_i q_i \right)$$

Fierz Transformation

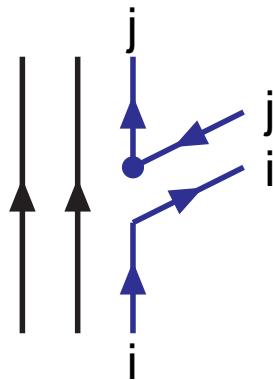
$$\begin{aligned} \mathcal{L}_I^{(S)} &= -\frac{\gamma}{4} \sum_{i,j} \left[+ \bar{q}_i q_j \cdot \bar{q}_j q_i + \bar{q}_i \gamma_\mu q_j \cdot \bar{q}_j \gamma^\mu q_i - \bar{q}_i \gamma_\mu \gamma_5 q_j \cdot \bar{q}_j \gamma^\mu \gamma^5 q_i \right. \\ &\quad \left. + \bar{q}_i \gamma_5 q_j \cdot \bar{q}_j \gamma^5 q_i - \frac{1}{2} \bar{q}_i \sigma_{\mu\nu} q_j \cdot \bar{q}_j \sigma^{\mu\nu} q_i \right] \end{aligned}$$

$$\chi_{ij}^S \sim \bar{q}_j q_i, \chi_{\mu,ij}^V \sim \bar{q}_j \gamma_\mu q_i, \chi_{\mu,ij}^A \sim \bar{q}_j \gamma_5 \gamma_\mu q_i$$

1. $g_\epsilon = g_\omega$, and $g_{a_0} = g_\rho$!?
2. What about f_π , g_{a_1} , etc. ?
3. $g_{q,ij}^V = g_{q,ij}^S = -g_{q,ij}^A = g_{q,ij}^P$

36 QPC: 3S_1 -model

Meson-Baryon Couplings from 3S_1 -Mechanism



3S_1 Interaction Lagrangian:

$$\mathcal{L}_I^{(V)} = \gamma \left(\sum_j \bar{q}_j \gamma_\mu q_j \right) \cdot \left(\sum_i \bar{q}_i \gamma^\mu q_i \right)$$

Fierz Transformation

$$\begin{aligned} \mathcal{L}_I^{(V)} &= -\frac{\gamma}{4} \sum_{i,j} \left[+ 4\bar{q}_i q_j \cdot \bar{q}_j q_i - 2\bar{q}_i \gamma_\mu q_j \cdot \bar{q}_j \gamma^\mu q_i \right. \\ &\quad \left. - 2\bar{q}_i \gamma_\mu \gamma_5 q_j \cdot \bar{q}_j \gamma^\mu \gamma^5 q_i - 4\bar{q}_i \gamma_5 q_j \cdot \bar{q}_j \gamma^5 q_i \right] \end{aligned}$$

$$\mathcal{L}_I = a\mathcal{L}_I^{(S)} + b\mathcal{L}_I^{(V)}$$

1. $g_{\epsilon,a_0} \sim (a - 4b)$, $g_{\omega,\rho} \sim (a - 2b)$!?
2. $g_{A_1,E_1} \sim -(a + 2b)$, $g_{\pi,\eta} \sim (a - 4b)$!?
3. But: $A_1 - B_1 - \pi(1300) \rightarrow$ Complicated sector!

37 QPC: 3P_0 -model

- $\rho \rightarrow e^+ e^-$: C.F. Identity & V.Royen-Weisskopf:

$$f_\rho = \frac{m_\rho^{3/2}}{\sqrt{2}|\psi_\rho(0)|} \Leftrightarrow \gamma_0 \left(\frac{2}{3\pi} \right)^{1/2} \frac{m_\rho^{3/2}}{|\psi_\rho(0)|} \rightarrow$$

$$\gamma_0 = \frac{1}{2}\sqrt{3\pi} = 1.535.$$

- OGE one-gluon correction: $\gamma = \gamma_0 \left(1 - \frac{16}{3} \frac{\alpha(m_M)}{\pi} \right)^{-1/2}$

$m_M \approx 1 \text{ GeV}$, $n_f = 3$, $\Lambda_{QCD} = 100 \text{ MeV}$: $\gamma \rightarrow 2.19$

- QPC (Quark-Pair-Creation) Model:
- Micu(1969), Carlitz & Kissinger(1970)
- Le Yaouanc et al(1973,1975)

38 QPC: 3P_0 -model and ESC04d/ESC08c

ESC04/08 Couplings and 3P_0 -Model Relations

Meson	$r_M [fm]$	X_M	γ_M	3P_0	ESC04	ESC08
$\pi(140)$	0.66	5/6	4.84	$f = 0.26$	0.26	0.27
$\rho(770)$	0.66	1	2.19	$g = 0.93$	0.78	0.73
$\omega(783)$	0.66	3	2.19	$g = 2.86$	3.08	3.51
$a_0(962)$	0.66	1	2.19	$g = 0.93$	0.82	0.90
$\epsilon(760)$	0.86	3	2.19	$g = 2.85$	3.22	4.36
$a_1(1270)$	0.66	$5\sqrt{2}/6$	2.19	$g = 2.51$	2.43	1.10

- QPC: 3P_0 -model relations: "bare"couplings (!)

$$g_\omega = 3g_\rho, \quad g_\epsilon = 3g_{a_0}, \quad \varepsilon_0(\lambda) \sim \bar{q}q(^3P_0)$$

$$g_{a_0} \approx g_\rho, \quad g_\epsilon \approx g_\omega \quad \varepsilon_a(\lambda) \sim \bar{q}q(^3S_1)$$

$$f_{NN a_1} \approx \frac{m_{a_1}}{m_\pi} f_{NN \pi} \text{ (CS, Schwinger67)}$$

39 QPC: $^3S_1 + ^3P_0$ -model and ESC08c

ESC08c Couplings and $^3S_1 + ^3P_0$ -Model Description

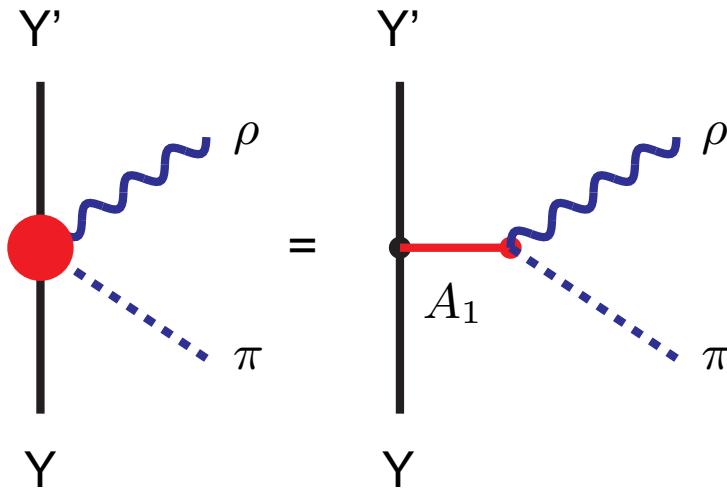
Meson	$r_M [fm]$	γ_M	3S_1	3P_0	QPC	ESC08c
$\pi(140)$	0.23	5.51	g=-3.54	g=+7.40	3.87 (4.07)	3.64
$\eta(957)$	0.71	2.22	g=-2.83	g=+5.93	3.10 (3.72)	3.07
$\rho(770)$	0.71	2.37	g=-0.24	g=+0.99	0.75 (0.92)	0.73
$\omega(783)$	0.71	2.35	g=-1.10	g=+4.60	3.50 (3.45)	3.51
$a_0(962)$	0.81	2.22	g=+0.28	g=+0.58	0.86 (0.90)	0.89
$\epsilon(760)$	0.71	2.37	g=+1.42	g=+2.96	4.38 (4.37)	4.36
$a_1(1270)$	0.61	2.09	g=-0.20	g=-0.84	-1.05 (-1.06)	-1.10
$f_1(1420)$	0.61	2.09	g=-0.72	g=-3.03	-3.76 (-3.25)	-0.91

- Weights $^3S_1 / ^3P_0$ are $A/B = 0.323/0.677 \approx 1 : 2$.
- SU(6)-breaking: (56) and (70) irrep mixing, $\varphi = -22^\circ$.
- QCD pair-creation constant: $\gamma(\alpha_s = 0.30) = 2.19$.
- QCD cut-off: $\Lambda_{QCD} = 244.3$ MeV, QQG form factor: $\Lambda_{QQG} = 986.2$ MeV.
- ESC08c: Pseudoscalar and axial mixing angles: -13° and $+50^\circ$.

40 ESC-model: extension to YN

SU(3)-Extension ESC to Hyperon-Nucleon

- MPE: Boson-dominance model:



$$\begin{aligned} g_{Y'Y(\rho\pi)_1} &= \hat{g}_{Y'YA_1} g_{A_1\rho\pi} \cdot (m_\pi^2/m_{A_1}^2) , \text{ e.g.} \\ g_{\Sigma\Lambda(\rho\pi)_1} &= \hat{g}_{\Sigma\Lambda A_1} g_{A_1\rho\pi} (m_\pi^2/m_{A_1}^2) \\ &= (\hat{g}_{\Sigma\Lambda A_1}/\hat{g}_{NN A_1}) g_{NN(\rho\pi)_1} \\ &= \frac{2}{\sqrt{3}}(1 - \alpha_A) g_{NN(\rho\pi)_1} \end{aligned}$$

41 Short-range Phenomenology-3

$SU(6)_{fs}$ -contents of the various potentials
on the isospin, spin basis.

(S, I)	$V = aV_{[51]} + bV_{[33]}$
$NN \rightarrow NN$	$(0, 1)$ $V_{NN}(I = 1) = \frac{4}{9}V_{[51]} + \frac{5}{9}V_{[33]}$
$NN \rightarrow NN$	$(1, 0)$ $V_{NN} = \frac{4}{9}V_{[51]} + \frac{5}{9}V_{[33]}$
$\Lambda N \rightarrow \Lambda N$	$(0, 1/2)$ $V_{\Lambda\Lambda} = \frac{1}{2}V_{[51]} + \frac{1}{2}V_{[33]}$
$\Lambda N \rightarrow \Lambda N$	$(1, 1/2)$ $V_{\Lambda\Lambda} = \frac{1}{2}V_{[51]} + \frac{1}{2}V_{[33]}$
$\Sigma N \rightarrow \Sigma N$	$(0, 1/2)$ $V_{\Sigma\Sigma} = \frac{17}{18}V_{[51]} + \frac{1}{18}V_{[33]}$
$\Sigma N \rightarrow \Sigma N$	$(1, 1/2)$ $V_{\Sigma\Sigma} = \frac{1}{2}V_{[51]} + \frac{1}{2}V_{[33]}$
$\Sigma N \rightarrow \Sigma N$	$(0, 3/2)$ $V_{\Sigma\Sigma} = \frac{4}{9}V_{[51]} + \frac{5}{9}V_{[33]}$
$\Sigma N \rightarrow \Sigma N$	$(1, 3/2)$ $V_{\Sigma\Sigma} = \frac{8}{9}V_{[51]} + \frac{1}{9}V_{[33]}$

ESC08-model: YN-results I

ESC08b YN+YY Fitting results (I):

$\Lambda p \rightarrow \Lambda p$	$135 \leq p_\Lambda \leq 300$	$12 \sigma_T$	$\chi^2 = 4.94$
$\Sigma^- p \rightarrow \Sigma^- p$	$142.5 \leq p_\Lambda \leq 167.5$	$6 \sigma_T$	$\chi^2 = 4.73$
$\Sigma^- p \rightarrow \Sigma^0 n$	$110.0 \leq p_\Lambda \leq 160.0$	$6 \sigma_T$	$\chi^2 = 5.78$
$\Sigma^- p \rightarrow \Lambda n$	$142.5 \leq p_\Lambda \leq 167.5$	$6 \sigma_T$	$\chi^2 = 4.55$
$\Sigma^+ p \rightarrow \Sigma^+ p$	$145.0 \leq p_\Lambda \leq 650.0$	$7 \sigma_T$	$\chi^2 = 4.04$
Total scattering data		37	$\chi^2 = 24.0$

- Capture ratio at rest: r_C : EXP= 0.468 ± 0.010 , THEORY= 0.466 , $\chi^2 = 0.06$

42 ESC08b-model: YN-results V

ESC08b YN+YY: Pseudo-data (constraints):

Low-Energy Parameters Λp :

a_s	-1.95	\pm	0.10	THEORY=	-2.56	$\Phi^2 =$	37.3
a_t	-1.86	\pm	0.01	THEORY=	-1.80	$\Phi^2 =$	31.7
r_s	2.90	\pm	0.10	THEORY=	3.14	$\Phi^2 =$	—
r_t	2.70	\pm	0.10	THEORY=	3.35	$\Phi^2 =$	—

Low-Energy Parameters $\Sigma^+ p$:

a_t	+0.62	\pm	0.05	THEORY=	0.78	$\Phi^2 =$	10.8
r_s	—	\pm	—	THEORY=	-1.33	$\Phi^2 =$	—

Low-Energy Parameters $\Lambda\Lambda$:

a_s	-1.00	\pm	0.10	THEORY=	-0.47	$\Phi^2 =$	111.0
r_s	—	\pm	—	THEORY=	8.19	$\Phi^2 =$	—

Low-Energy Parameters ΞN :

$a_t(I = 0)$	-6.00	\pm	0.10	THEORY=	-0.03	$\Phi^2 =$	—
$a_t(I = 1)$	-6.00	\pm	0.05	THEORY=	+1.99	$\Phi^2 =$	—

Spin-orbit constraint Λp :

$K_\Lambda(V)$	0.00	\pm	0.10	THEORY=	1.65	$\Phi^2 =$	67.7
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43 G-matrix ESC-models

Partial wave contributions to $U_\Lambda(\rho_0)^{(a)}$

NSC97e	-12.7	-25.5	2.1	0.5	3.2	-1.2	-1.1	-34.7
NSC97f	-14.3	-22.4	2.4	0.5	4.0	-0.7	-1.2	-31.7
	1S_0	3S_1	1P_1	3P_0	3P_1	3P_2	D	sum
ESC04a	-13.7	-20.5	0.6	0.2	0.5	-4.5	-1.0	-38.5
ESC04d	-13.6	-26.6	3.2	-0.2	0.9	-6.4	-1.4	-44.1
ESC08a	-13.1	-21.9	3.4	-0.0	1.3	-4.5	-1.6	-36.5
ESC08b	-12.3	-19.7	2.7	-0.2	1.5	-4.2	-1.7	-34.0
ESC08b*	-13.3	-25.1	2.5	-0.2	1.4	-4.5	-1.7	-41.0

- (a): QTQ-approximation, ESC08*: CIES-method
 - MPP: $\Delta U_\Lambda(\rho_0) \approx +(4 - 6)$ MeV
 - private communication Y. Yamamoto

44 G-matrix ESC-models

Partial wave contributions to $U_\Sigma(\rho_0)$

model	T	1S_0	3S_1	1P_1	3P_0	3P_1	3P_2	D	U_Σ	Γ_Σ
NSC97f	1/2	14.9	-9.6	1.9	2.3	-4.0	0.4	-0.4	-13.9	16.0
	3/2	-12.2	-4.2	-3.8	-1.8	5.5	-2.7	-0.2		
ESC04d	1/2	6.5	-21.0	2.6	2.4	-6.7	-1.7	-0.9	-26.0	
	3/2	-10.1	14.0	-8.5	-2.6	5.9	-5.7	-0.2		
ESC06d	1/2	7.2	-21.5	1.9	2.3	-6.1	-1.0	-0.8	-1.2	
	3/2	-10.8	39.1	-10.6	-2.5	6.0	-4.5	-0.1		
ESC06d*	1/2	8.1	-20.5	2.1	2.3	-6.0	-1.0	-0.8	+8.2	
	3/2	-10.1	43.8	-10.6	-2.2	6.3	-3.6	-0.0		
ESC08b	1/2	10.3	-26.2	2.5	2.2	-7.9	-1.7	-0.8	+20.3	35.9
	3/2	-10.6	52.7	-6.2	-2.0	7.4	0.8	-0.1		

- MPP: $\Delta U_\Sigma(\rho_0) \approx + (4 - 6) \text{ MeV}$
- private communication Y. Yamamoto

VLS and VLSA Spin-orbit ESC-models, I

Strengths of Λ spin-orbit potential-integrals

$$K_{\Lambda} = K_{S,\Lambda} + K_{A,\Lambda} \text{ where}$$

$$K_{S,\Lambda} = -\frac{\pi}{3} S_{SLS} \text{ and } K_{A,\Lambda} = -\frac{\pi}{3} S_{ALS} \text{ with}$$

$$S_{SLS,ALS} = \frac{3}{q} \int_0^\infty r^3 j_1(qr) V_{SLS,ALS}(r) dr .$$

	K_S	K_A	K_{Λ}	$\Delta E_{LS} (^9_{\Lambda}Be)$
NHC-D	30.7	-9.3	21.4	0.15*
ESC04b	16.0	-11.1	4.9	
ESC04d	22.3	-11.9	10.4	
ESC08c	20.9?	-19.5?	2.3 (!)	
Experiment				$0.043 \pm 0.002^{**}$

• private communication Y. Yamamoto

*) E. Hiyama et al, Phys. Rev. Lett. 85 (2000) 270.

**) H.Tamura, Nucl.Phys. A691 (2001) 86c-92c.

VLS and VLSA Spin-orbit ESC-models, II

Strengths of Λ spin-orbit potential-integrals

$$K_{\Lambda} = K_{S,\Lambda} + K_{A,\Lambda} \text{ where}$$

$$K_{S,\Lambda} = -\frac{\pi}{3} S_{SLS} \text{ and } K_{A,\Lambda} = -\frac{\pi}{3} S_{ALS} \text{ with}$$

$$S_{SLS,ALS} = \frac{3}{q} \int_0^{\infty} r^3 j_1(qr) V_{SLS,ALS}(r) dr .$$

	K_S	K_A	$K_{\Lambda}^{(0)}$	$K_{\Lambda}(BDI)$	$K_{\Lambda}(Pair)$	ΔE_{LS}
ESC04b	16.0	-8.7	7.3	(-2.4)	(-3.3)	
ESC04d	22.3	-6.9	15.4	(-5.0)	(-6.9)	
NILS06d	21.5	-6.1	15.4	(-5.1)	(-6.6)	
ESC07	20.9	-9.6	11.3	(-4.7)	(-5.2)	
NHC-D	30.7	-5.9	24.8	(-3.4)	—	0.15*
NHC-F	29.7	-6.7	23.0	(-3.8)	—	0.20*
Experiment						0.031

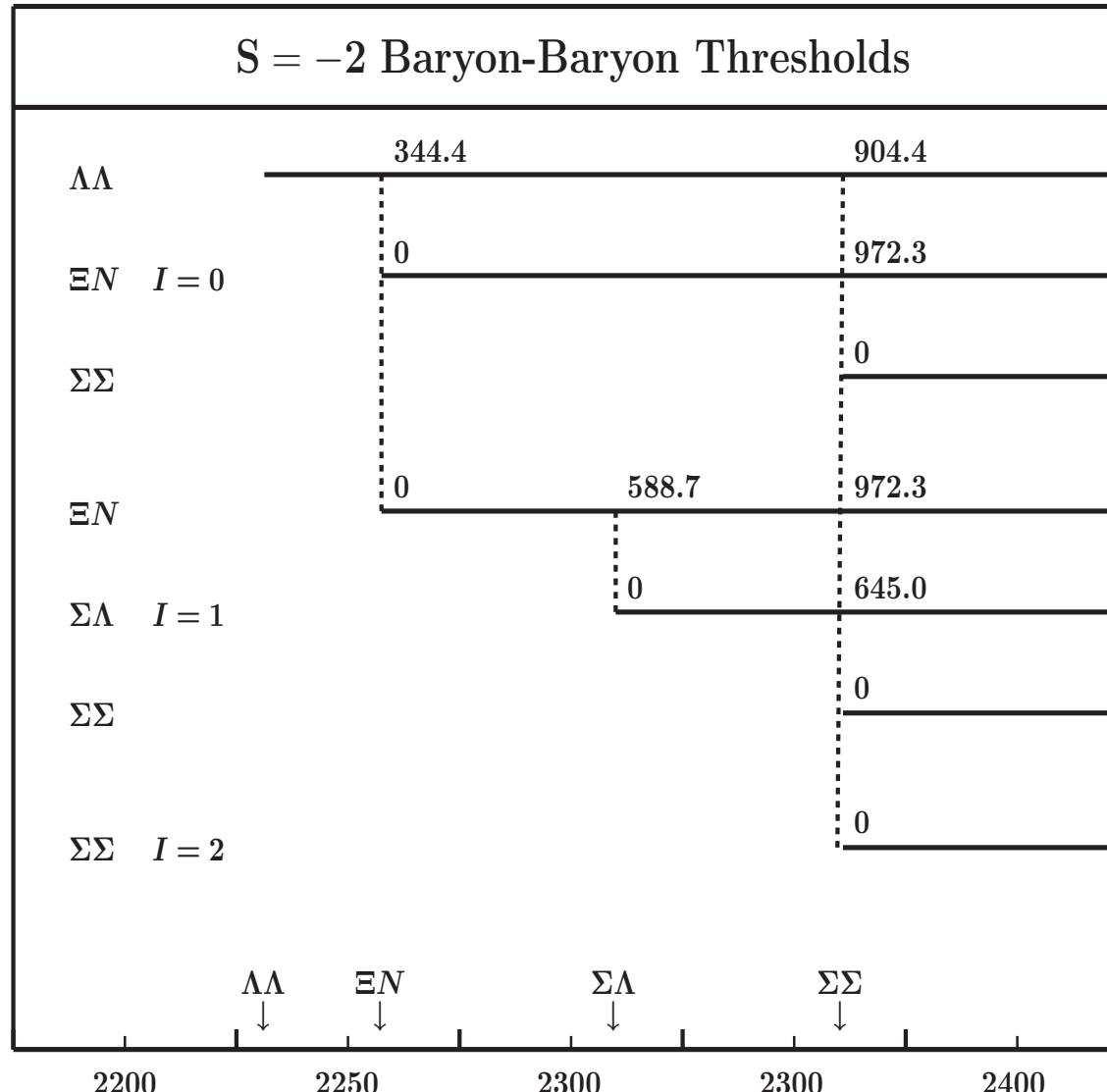
- private communication Y. Yamamoto

*) E. Hiyama et al, Phys. Rev. Lett. 85 (2000) 270.

**) H.Tamura, Nucl.Phys. A691 (2001) 86c-92c.

45 ESC-models: $S = -2$ YY,YN

YY: The $\Lambda\Lambda$ -systems etc. ESC2004/06



1

46 ESC-models: YY

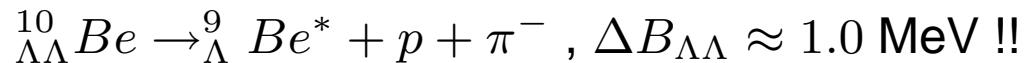
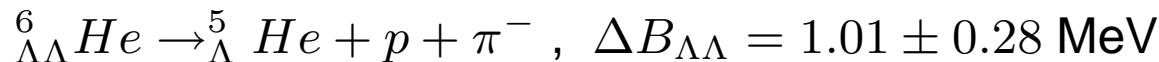
YY: The $\Lambda\Lambda$ -systems ESC2004/07

- Danyz et al (1963) , Dalitz et al (1989):



- Dover, Maui 1993: $|V_{\Lambda\Lambda}(^1S_0)| \approx |V_{NN}(^1S_0)|$
→ strong attraction in $\Lambda\Lambda$ -systems, H (?!)

- KEK-373: NAGARA-event (2001), Nakazawa et al



- Soft-core models: NSC89, NSC97:

$$|V_{\Lambda\Lambda}(\epsilon)| < |V_{\Lambda N}(\epsilon)| < |V_{NN}(\epsilon)|$$

→ weak attraction/repulsion in $\Lambda N, \Xi N$ -systems.

- ESC04d-model: $\Delta B_{\Lambda\Lambda} \approx 1.0 \text{ MeV} !!$

Ξ -well-depth = -18.7 MeV ≈ experiment -(14-16) MeV (!?)

ESC-models: YY

$\Delta B_{\Lambda\Lambda}$ Nijmegen ESC-models:

model	$\Delta B_{\Lambda\Lambda}$ MeV	$P_{\Xi N}()$
ESC04a	1.36	0.44
ESC04b	1.37	0.45
ESC04c	0.97	1.15
ESC04d	0.98	1.18
ESC07	0.80	
NSC97f	0.34	0.19
NHC-D ^a	1.05	0.14
exp ^b	1.01 ± 0.20	

- a: NHC-D $r_{HC} = 0.53$ fm.
- b: H. Takahashi et al, PRL 87, 212502 (2001)

47 Baryon-baryon Channels $S = -2$

$SU(6)_{fs}$ -contents spin-space odd $^1S_0, ^3P, ^1D_2, \dots$
potentials on the spin-isospin basis.

(S, I)	$V = aV_{[51]} + bV_{[33]}$
$\Lambda\Lambda \rightarrow \Lambda\Lambda$	$(0, 0) \quad V_{\Lambda\Lambda, \Lambda\Lambda} = \frac{1}{2}V_{[51]} + \frac{1}{2}V_{[33]}$
$\Xi N \rightarrow \Xi N$	$(0, 0) \quad V_{\Xi N, \Xi N} = \frac{1}{3}V_{[51]} + \frac{2}{3}V_{[33]}$
$\Sigma\Sigma \rightarrow \Sigma\Sigma$	$(0, 0) \quad V_{\Sigma\Sigma, \Sigma\Sigma} = \frac{11}{18}V_{[51]} + \frac{7}{18}V_{[33]}$
$\Xi N \rightarrow \Xi N$	$(0, 1) \quad V_{\Xi N, \Xi N} = \frac{7}{9}V_{[51]} + \frac{2}{9}V_{[33]}$
$\Sigma\Lambda \rightarrow \Sigma\Lambda$	$(0, 1) \quad V_{\Sigma\Lambda, \Sigma\Lambda} = \frac{2}{3}V_{[51]} + \frac{1}{3}V_{[33]}$
$\Sigma\Sigma \rightarrow \Sigma\Sigma$	$(0, 2) \quad V_{\Sigma\Sigma, \Sigma\Sigma} = \frac{4}{9}V_{[51]} + \frac{5}{9}V_{[33]}$

48 Baryon-baryon Channels $S = -2$

$SU(6)_{fs}$ -contents of the spin-space even $^3S_1, ^1P_1, ^3D, \dots$
potentials on the spin-isospin basis.

$$(S, I) \quad V = aV_{[51]} + bV_{[33]}$$

$$\Xi N \rightarrow \Xi N \quad (1, 0) \quad V_{\Xi N, \Xi N} = \frac{5}{9}V_{[51]} + \frac{4}{9}V_{[33]}$$

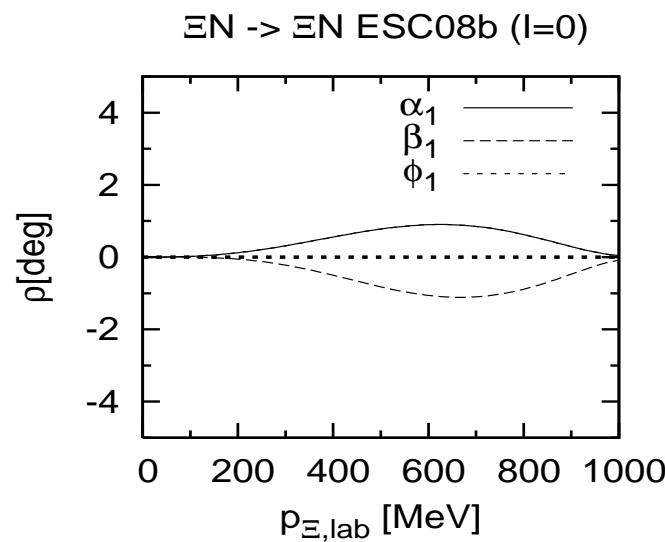
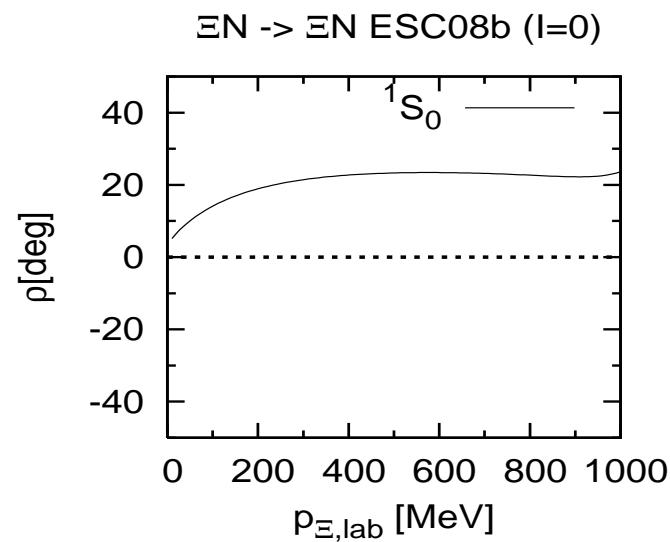
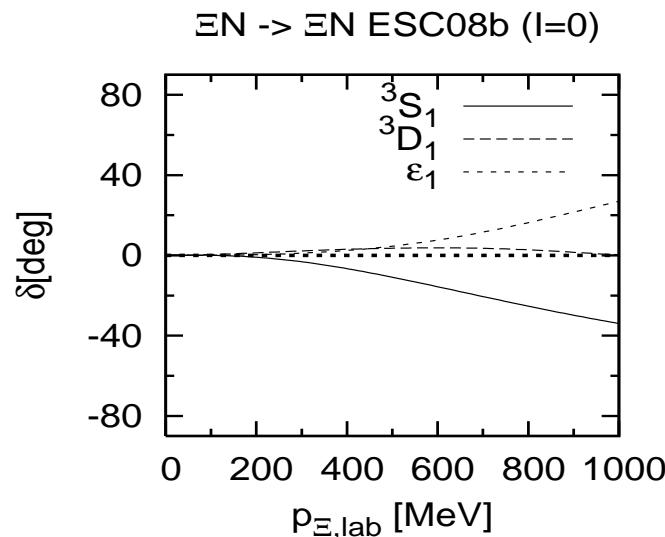
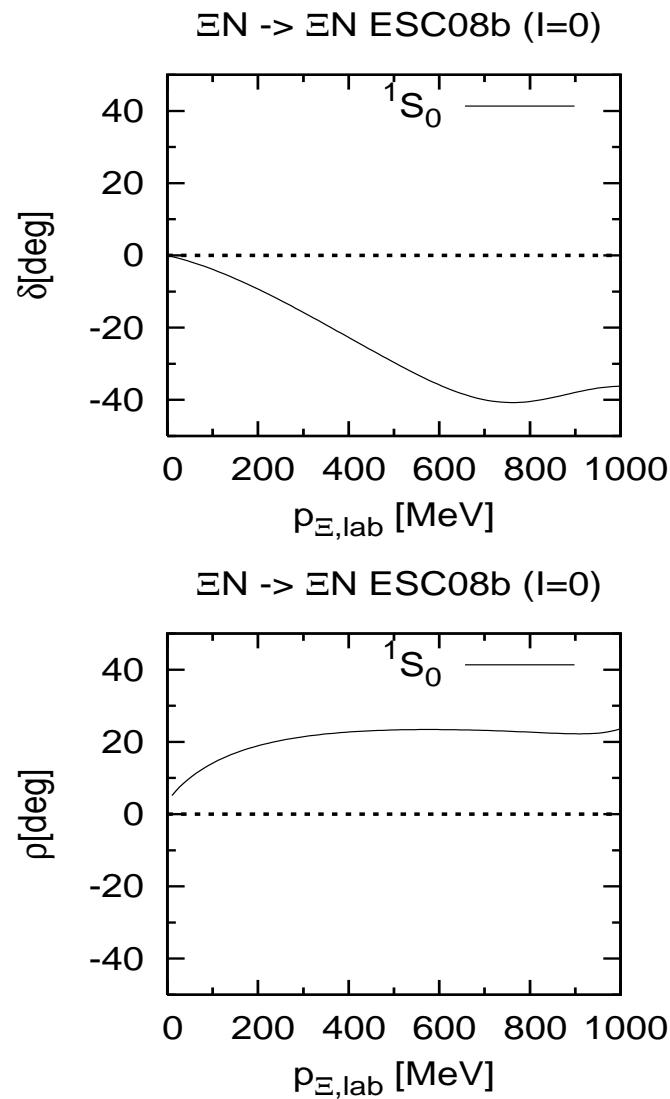
$$\Xi N \rightarrow \Xi N \quad (1, 1) \quad V_{\Xi N, \Xi N} = \frac{17}{27}V_{[51]} + \frac{10}{27}V_{[33]}$$

$$\Sigma \Lambda \rightarrow \Sigma \Lambda \quad (1, 1) \quad V_{\Sigma \Lambda, \Sigma \Lambda} = \frac{2}{3}V_{[51]} + \frac{1}{3}V_{[33]}$$

$$\Sigma \Sigma \rightarrow \Sigma \Sigma \quad (1, 1) \quad V_{\Sigma \Sigma, \Sigma \Sigma} = \frac{16}{27}V_{[51]} + \frac{11}{27}V_{[33]}$$

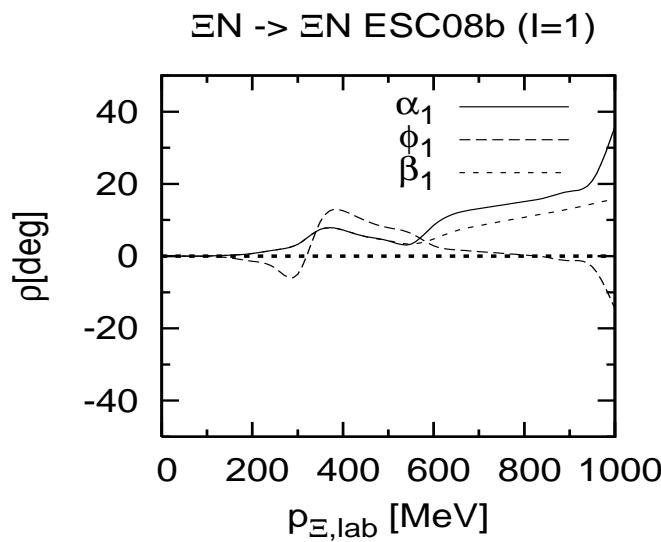
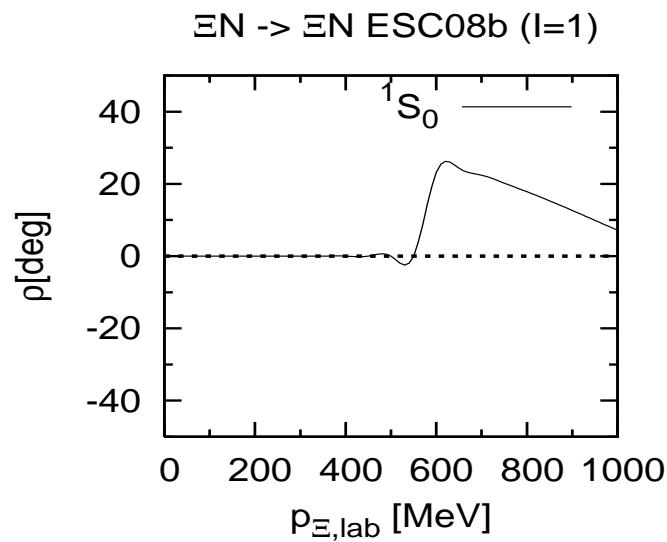
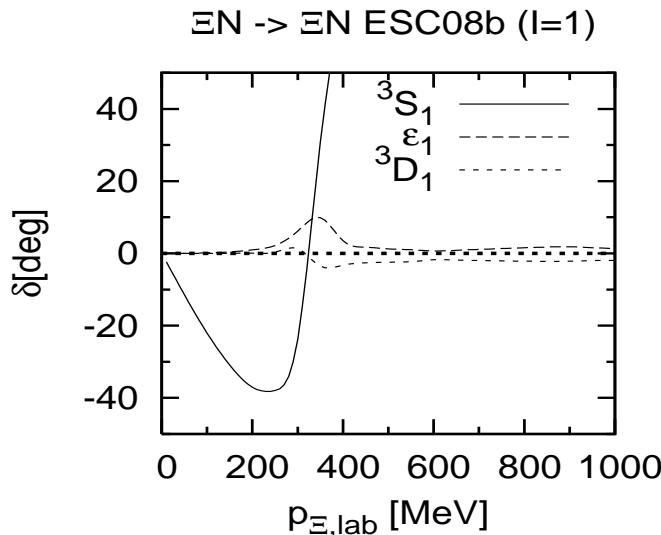
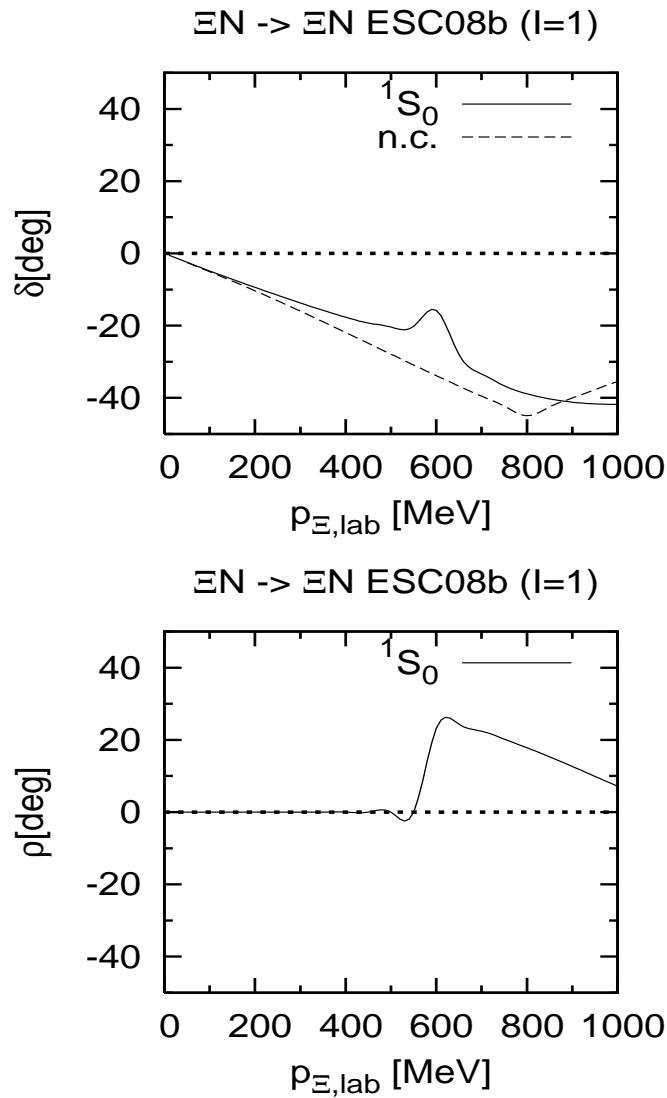
ΞN -phases

ΞN phases



ΞN -phases

ΞN phases



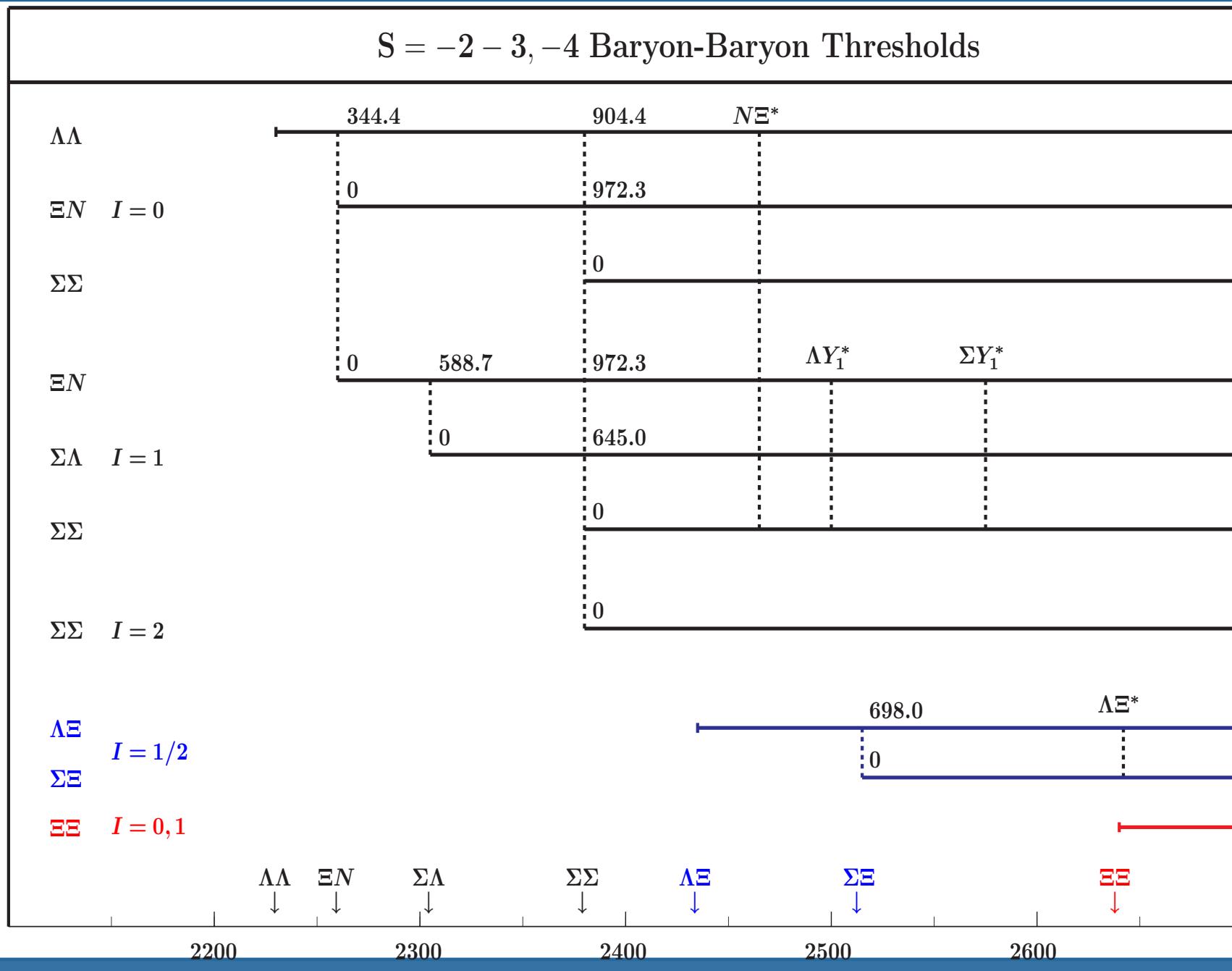
49 G-matrix ESC-models

Partial wave contributions to $U_{\Xi}(\rho_0)$ at normal density.

model		1S_0	3S_1	1P_1	3P_0	3P_1	3P_2	U_{Ξ}
NHC-D	$T = 0$	-4.5	2.6	-1.8	-0.2	-0.6	-1.7	
	$T = 1$	0.2	5.3	-2.6	0.0	-2.9	-5.6	-11.9
ESC04d	$T = 0$	6.4	-19.6	1.1	1.2	-1.3	-2.0	
	$T = 1$	6.4	-5.0	-1.0	-0.6	-1.4	-2.8	-18.7
ESC08a	$T = 0$	6.1	-0.9	-0.3	-2.8	1.4	-1.0	
	$T = 1$	21.8	-31.7	2.5	0.3	-3.7	-0.6	-9.0
ESC08b	$T = 0$	2.1	2.0	-0.6	-1.3	-0.1	-0.7	
	$T = 1$	26.6	-40.3	3.0	-0.6	-3.7	-1.3	-14.7
ESC08a'' (CONr)	$T = 0$	3.6	-6.7	0.1	-4.4	1.7	-0.6	
	$T = 1$	13.0	-13.6	2.3	0.8	-2.1	1.0	-4.9
ESC08c	$T = 0$	-1.4	4.6	-0.1	-0.5	-2.0	-0.6	
	$T = 1$	15.8	-21.9	1.1	-0.8	-1.7	0.8	-6.9

- MPP: $\Delta U_{\Xi}(\rho_0) \approx +(4 - 6) \text{ MeV}$
- private communication Y. Yamamoto

50 ESC-models: $S = -2, -3, -4$ YY, YN



51 ESC08: $\Lambda/\Sigma\Xi$ - and $\Xi\Xi$ -systems

ESC08: $\Lambda\Xi, \Sigma\Xi$ - and $\Xi\Xi$ -systems

- R-conjugation (Gell-Mann 1961): \Rightarrow

Connection ($NN, \Lambda N/\Sigma N$) and ($\Xi\Xi, \Lambda/\Sigma\Xi$ -channels:

$$\begin{aligned} p &\leftrightarrow \Xi^- , \quad n \leftrightarrow \Xi^0 , \quad \Lambda \leftrightarrow \Lambda , \quad \Sigma^0 \leftrightarrow \Sigma^0 \\ K^+ &\leftrightarrow K^- , \quad K^0 \leftrightarrow \bar{K}^0 , \quad \eta \leftrightarrow \eta , \quad \pi^0 \leftrightarrow \pi^0 \end{aligned}$$

- For the BB-states:

$$\begin{aligned} R\psi_{27}(Y, I, I_3) &= \psi_{27}(-Y, I, -I_3), & R\psi_{10}(Y, I, I_3) &= \psi_{10*}(-Y, I, -I_3), \\ R\psi_{8s}(Y, I, I_3) &= \psi_{8s}(-Y, I, -I_3), \\ R\psi_{8a}(Y, I, I_3) &= -\psi_{8a}(-Y, I, -I_3), & R\psi_1(Y, I, I_3) &= \psi_1(-Y, I, -I_3), \end{aligned}$$

\Rightarrow in SU(3)-structure ($\Xi\Xi, \Lambda/\Sigma\Xi$)-potentials compared to ($NN, \Lambda\Sigma N$)
the SU3-irreps $\{10\} \leftrightarrow \{10^*\}$ are interchanged!

- R-conjugation $\ni \text{SU}(3)_f$, interactions not invariant(!)

52 ESC08: $\Lambda/\Sigma\Xi$ - and $\Xi\Xi$ -systems

$\Lambda/\Sigma\Xi, \Xi\Xi$: PW's and SU3-irreps

$SU(3)_f$ -contents of the various potentials
on the isospin basis.

Space-spin antisymmetric states $^1S_0, ^3P, ^1D_2, \dots$

$$\Xi\Xi \rightarrow \Xi\Xi \quad I = 1 \quad V_{\Xi\Xi}(I = 1) = V_{27}$$

$$\Lambda\Xi \rightarrow \Lambda\Xi \quad V_{\Lambda\Lambda}(I = \frac{1}{2}) = (9V_{27} + V_{8_s})/10$$

$$\Lambda\Xi \rightarrow \Sigma\Xi \quad I = \frac{1}{2} \quad V_{\Lambda\Sigma}(I = \frac{1}{2}) = (-3V_{27} + 3V_{8_s})/10$$

$$\Sigma\Xi \rightarrow \Sigma\Xi \quad V_{\Sigma\Sigma}(I = \frac{1}{2}) = (V_{27} + 9V_{8_s})/10$$

$$\Sigma\Xi \rightarrow \Sigma\Xi \quad I = \frac{3}{2} \quad V_{\Sigma\Sigma}(I = \frac{3}{2}) = V_{27}$$

53 ESC08: $\Lambda/\Sigma\Xi$ - and $\Xi\Xi$ -systems

$\Lambda/\Sigma\Xi, \Xi\Xi$: PW's and SU3-irreps

$SU(3)_f$ -contents of the various potentials
on the isospin basis.

Space-spin symmetric states ${}^3S_1, {}^1P_1, {}^3D, \dots$

$$\Xi\Xi \rightarrow \Xi\Xi \quad I = 0 \quad V_{\Xi\Xi}(I = 0) = V_{10} \text{ (!)}$$

$$\Lambda\Xi \rightarrow \Lambda\Xi \quad V_{\Lambda\Lambda}(I = \frac{1}{2}) = (V_{10} + V_{8_a})/2$$

$$\Lambda\Xi \rightarrow \Sigma\Xi \quad I = \frac{1}{2} \quad V_{\Lambda\Sigma}(I = \frac{1}{2}) = (V_{10} - V_{8_a})/2$$

$$\Sigma\Xi \rightarrow \Sigma\Xi \quad V_{\Sigma\Sigma}(I = \frac{1}{2}) = (V_{10} + V_{8_a})/2$$

$$\Sigma\Xi \rightarrow \Sigma\Xi \quad I = \frac{3}{2} \quad V_{\Sigma\Sigma}(I = \frac{3}{2}) = V_{10^\star} \text{ (!)}$$

54 $\Lambda/\Sigma\Xi, \Xi\Xi$: $SU(6)_{fs}$ -irreps

$SU(6)_{fs}$ -contents of the various potentials
on the isospin, spin basis.

(S, I)	$V = aV_{[51]} + bV_{[33]}$
$\Xi\Xi \rightarrow \Xi\Xi$	$(0, 1)$
	$V_{\Xi\Xi} = \frac{4}{9}V_{[51]} + \frac{5}{9}V_{[33]}$
$\Xi\Xi \rightarrow \Xi\Xi$	$(1, 0)$
	$V_{\Xi\Xi} = \frac{8}{9}V_{[51]} + \frac{1}{9}V_{[33]}$
$\Lambda\Xi \rightarrow \Lambda\Xi$	$(0, 1/2)$
	$V_{\Lambda\Lambda} = \frac{1}{2}V_{[51]} + \frac{1}{2}V_{[33]}$
$\Lambda\Xi \rightarrow \Lambda\Xi$	$(1, 1/2)$
	$V_{\Lambda\Lambda} = \frac{13}{18}V_{[51]} + \frac{5}{18}V_{[33]}$
$\Sigma\Xi \rightarrow \Sigma\Xi$	$(0, 1/2)$
	$V_{\Sigma\Sigma} = \frac{17}{18}V_{[51]} + \frac{1}{18}V_{[33]}$
$\Sigma\Xi \rightarrow \Sigma\Xi$	$(1, 1/2)$
	$V_{\Sigma\Sigma} = \frac{13}{18}V_{[51]} + \frac{5}{18}V_{[33]}$
$\Sigma\Xi \rightarrow \Sigma\Xi$	$(0, 3/2)$
	$V_{\Sigma\Sigma} = \frac{4}{9}V_{[51]} + \frac{5}{9}V_{[33]}$
$\Sigma\Xi \rightarrow \Sigma\Xi$	$(1, 3/2)$
	$V_{\Sigma\Sigma} = \frac{4}{9}V_{[51]} + \frac{5}{9}V_{[33]}$

55 $\Lambda\Xi$ and $\Sigma\Xi$: $SU(6)_{fs}$ -irreps

$S = -3, \Lambda\Xi, \Sigma\Xi$: Low-energy parameters

- Effective -range parameters [fm]:

$$ESC08c : \quad a_{\Lambda\Xi}(^1S_0) = \textcolor{blue}{-9.83}, \quad r_{\Lambda\Xi}(^1S_0) = 2.38, \quad (9V_{27} + V_{8_s})/10, \quad I = 1/2$$
$$a_{\Lambda\Xi}(^3S_1) = \textcolor{blue}{-12.9}, \quad r_{\Lambda\Xi}(^3S_1) = 2.00, \quad (V_{10} + V_{8_a})/2, \quad I = 1/2$$

$$a_{\Sigma\Xi}(^1S_0) = -2.80, \quad r_{\Sigma\Xi}(^3S_1) = 2.45, \quad V_{27}, \quad I = 3/2$$

$$a_{\Sigma\Xi}(^3S_1) = \textcolor{blue}{-10.9}, \quad r_{\Sigma\Xi}(^3S_1) = 1.92, \quad V_{10*}, \quad I = 3/2.$$

$$ESC08c' : \quad a_{\Lambda\Xi}(^1S_0) = \textcolor{blue}{-8.14}, \quad r_{\Lambda\Xi}(^1S_0) = 2.44, \quad (9V_{27} + V_{8_s})/10, \quad I = 1/2$$
$$a_{\Lambda\Xi}(^3S_1) = \textcolor{blue}{-0.57}, \quad r_{\Lambda\Xi}(^3S_1) = 7.17, \quad (V_{10} + V_{8_a})/2, \quad I = 1/2$$

$$a_{\Sigma\Xi}(^1S_0) = -22.9, \quad r_{\Sigma\Xi}(^3S_1) = 1.97, \quad V_{27}, \quad I = 3/2$$

$$a_{\Sigma\Xi}(^3S_1) = \textcolor{red}{+6.47}, \quad r_{\Sigma\Xi}(^3S_1) = 1.45, \quad V_{10*}, \quad I = 3/2.$$

- ESC08c': 3S_1 -bound state? YES (!?)

56 ΞΞ: $SU(6)_{fs}$ -irreps

$S = -4, \Xi\Xi$: Low-energy parameters

- Effective -range parameters [fm]:

$$ESC08a : a_{\Xi\Xi}(^1S_0) = -18.8 , \quad r_{\Xi\Xi}(^1S_0) = 1.81, \quad V_{27}, \quad I = 1$$

$$a_{\Xi\Xi}(^3S_1) = +0.73 , \quad r_{\Xi\Xi}(^3S_1) = 0.16, \quad V_{10}, \quad I = 0$$

$$ESC08b : a_{\Xi\Xi}(^1S_0) = 122.5 , \quad r_{\Xi\Xi}(^1S_0) = 1.68, \quad V_{27}, \quad I = 1$$

$$a_{\Xi\Xi}(^3S_1) = +0.82 , \quad r_{\Xi\Xi}(^3S_1) = 0.49, \quad V_{10}, \quad I = 0$$

$$ESC08c : a_{\Xi\Xi}(^1S_0) = -7.25 , \quad r_{\Xi\Xi}(^1S_0) = 2.00, \quad V_{27}, \quad I = 1$$

$$a_{\Xi\Xi}(^3S_1) = +0.53 , \quad r_{\Xi\Xi}(^3S_1) = 1.63, \quad V_{10}, \quad I = 0$$

$$ESC08c' : a_{\Xi\Xi}(^1S_0) = +6.96 , \quad r_{\Xi\Xi}(^1S_0) = 1.49, \quad V_{27}, \quad I = 1$$

$$a_{\Xi\Xi}(^3S_1) = +0.09 , \quad r_{\Xi\Xi}(^3S_1) = 85.8, \quad V_{10}, \quad I = 0$$

- ESC08b: 1S_0 -bound state!!
- ESC08c: 1S_0 -bound state? NO/YES (!?)

$$\bullet \kappa = (1 - \sqrt{1 - 2r/a})/r \sim 1/a (r \ll a), \quad E_B \approx \kappa^2/m_B$$

57 Conclusions and Status YN-interactions

Conclusions and Prospects

1. High-quality Simultaneous Fit/Description $NN \oplus YN$,
OBE, TME, MPE meson-exchange dynamics.
 $SU_f(3)$ -symmetry, (Non-linear) chiral-symmetry.
2. NN,YN,YY: Couplings $SU_f(3)$ -symmetry, 3P_0 -dominance QPC,
Quark-core effect: $^3S_1(\Sigma N, I = 3/2)$ is strongly repulsive,
3. Scalar-meson nonet structure \Leftrightarrow **Nagara $\Delta B_{\Lambda\Lambda}$ values**.
4. **NO S=-1 Bound-States, NO $\Lambda\Lambda$ -Bound-State**,
5. Prediction: $D_{\Xi N} = \Xi N(I = 1, ^3S_1)$ B.S.!, $D_{\Xi\Xi} = \Xi\Xi(I = 1, ^1S_0)$ B.S. ??!

Status meson-exchange description of the YN/YY-interactions:

- a. ESC08: Excellent G-matrix predictions for the $U_\Lambda, U_\Sigma, U_\Xi$ well-depth's,
 ΛN spin-spin and spin-orbit, and Nagara-event okay.
 - b. Similar role **tensor-force** in 3S_1 NN-, $\Lambda/\Sigma N$ -, ΞN -, and $\Lambda/\Sigma\Xi$ -channels.
 - c. Neutron Star mass $M/M_\odot = 1.44 \Leftrightarrow$ Multi-Pomeron Repulsion.
-
- **JPARC, FINUDA, FAIR: new data Hypernuclei, $\Sigma^+ P, \Lambda Pi, \Xi N$!!**
 - **RHIC: new data Exotic D-Hyperons $\Lambda\Lambda, \Lambda\Xi, \Xi\Xi$!!**